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Improving the Effectiveness of Introductory Eco-design Activities within Industry through the Development of an Introductory Eco-design Process

Molly Buckingham

A THESIS SUBMITTED FOR THE DEGREE OF MASTER OF
PHILOSOPHY

University of Bath

Department of Mechanical Engineering

October 2015

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List of Publications

The following list of related publications have been produced during this project and subsequent to its completion.

1. Buckingham, Molly, Dekoninck, Elies and McMahon, Chris. "Improving eco-design projects through better understanding of the company characteristics and business context." *DS 75-3: Proceedings of the 19th International Conference on Engineering Design (ICED13) Design For Harmonies, Vol. 3: Design Organisation and Management*, Seoul, Korea 19-22.08. 2013.
2. Buckingham, Molly, et al. "Supporting eco-design implementation within small and large companies." *DS 77: Proceedings of the DESIGN 2014 13th International Design Conference*. 2014.
3. Buckingham, Molly, Dekoninck, Elies. "The importance of understanding the business context when planning eco-design activities." *KES Transaction on Sustainable Design and Manufacturing: Vol 1 No 1, Special Edition – Sustainable Design and Manufacturing 2014: pp.374-385*. 2014
4. Domingo, Lucie, et al. "The importance of understanding the business context when planning eco-design activities." *Journal of Industrial and Production Engineering* 32.1 (2015): 3-11.

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A Brief note on the Company

The descriptions of the Company involved in the KTP Project relate to a specific moment in their history and development. Many of the Company features described here are known to be outdated due to significant changes and developments both in the organisation and product development process at the Company since completion. Any reviews of processes and procedures reported here, aim to contribute to the understanding of eco-design in industry in general.

Abstract

The research project set out with the aim of investigating how introductory eco-design projects can promote and support ongoing eco-design development within design and manufacturing companies. To meet this aim, the dissertation presents a body of research that supports the development of an Introductory Eco-design Process. The Introductory Eco-design Process provides a structured approach for those undertaking their first eco-design project. The activities and sequence that make up the process have been identified to ensure that introductory projects increase eco-design knowledge and understanding, whilst promoting and supporting ongoing development.

Adopting an inductive approach, the Introductory Eco-design Process has been developed by collating the learning outcomes from three key research phases; observation, pattern identification and theory development. The observation phase consisted of a literature review and introductory eco-design case study description. The literature review identifies a set of characteristics that describe companies in the nascent stage of eco-design development and finds that existing experience, recommendations and methodologies are poorly matched to these characteristics. The case study description provides a detailed examination of an introductory eco-design project that was found to poorly embed eco-design practice. This provides learning relating to the practical and psychological opportunities and barriers faced when introducing eco-design in a design and manufacturing firm. The pattern identification phase consisted of two retrospective analyses of the case study achieved through subsequent interviews, documental analysis and a review of design activity. Collating this retrospective research enabled key recommendations for structuring eco-design projects and identified a set of company characteristics found to have greatest impact on introductory eco-design activities and outcomes. Bringing the learning outcomes from each of these phases together, the Introductory Eco-design Process emerged as an initial theory. Acknowledging the inherent limitations of applying an inductive approach to a single case study, the final chapter tests this theory against other industrial backgrounds. The exercise finds that the process can successfully support eco-design introduction in other industrial contexts.

1. Introduction to the Research Project

The opening section of this dissertation describes its academic and industrial background and the justification for continued development in this this topic area. The research aims, objectives and questions are then set out, followed by the methodology chosen to conduct the research project. Finally the structure of the dissertation is described.

1.1 Research Focus

The dissertation focuses on the introduction of eco-design within design and manufacturing companies, with particular focus on the first project undertaken. The research is centred on an introductory eco-design project that took place during a two year Knowledge Transfer Partnership (KTP). The KTP Scheme is a government funded initiative that *“supports UK businesses wanting to improve their competitiveness, productivity and performance by accessing the knowledge and expertise available within UK Universities and Colleges.”* (2011). Analysis of the project’s activities and outcomes enables the examination of certain phenomenon rarely focussed on in eco-design literature; the specific challenges presented by the introductory eco-design context, the role that the first eco-design project plays in introducing eco-design, and the salient features required to encourage ongoing development. The research outcome is the Introductory Eco-design Process. The Introductory Eco-design Process has been designed to ensure that introductory eco-design projects provide sufficient knowledge development whilst also motivating and supporting ongoing development within design and manufacturing firms.

Although there is a body of knowledge on eco-design implementation and several methodologies that support the introduction of a continuous improvement process for eco-design, all of which by default include eco-design introduction, there has been very little work that isolates the nascent stage. The academic isolation of this phase has been conducted to address the pilot project character observed within industrial eco-design and the very real challenges faced in overcoming this introductory phase. The area of focus for this research is shown in Figure 1.

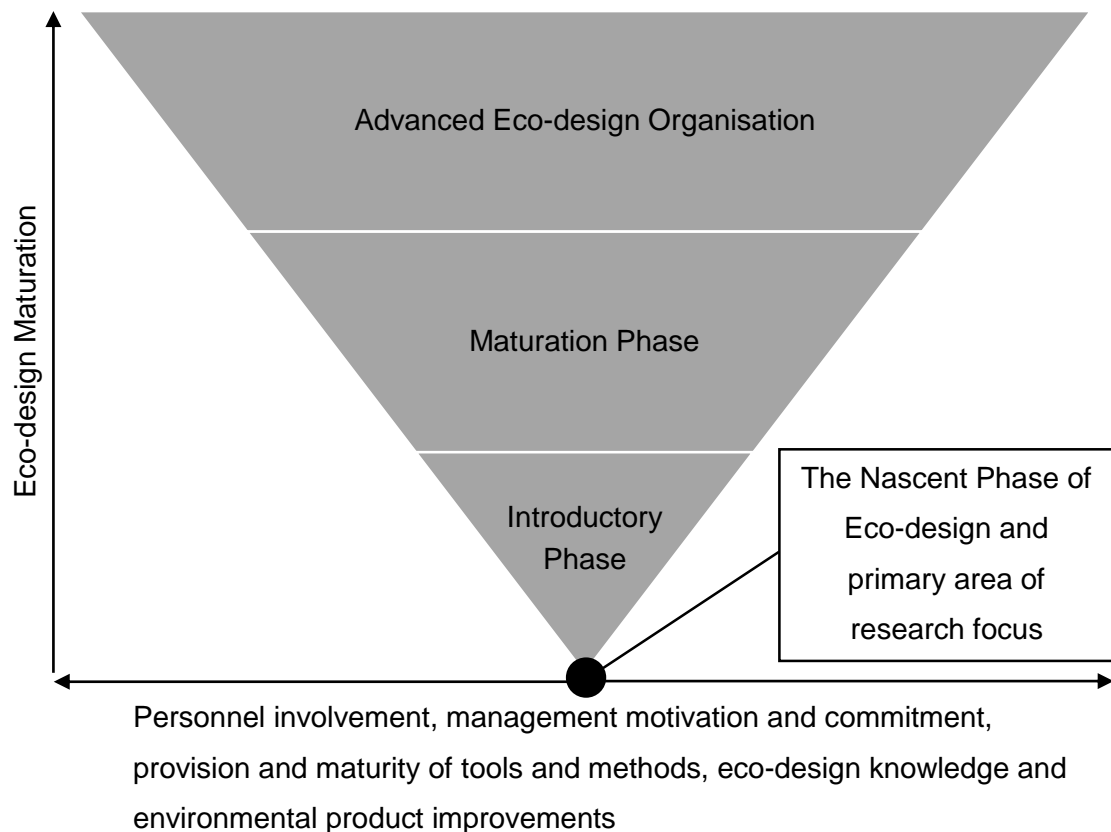


Figure 1: Defining the Focus of this Research; the Nascent Phase of Eco-design within the Context of Eco-design Maturation

1.2 Background to Research

The origins of the environmental design or eco-design movement can be traced back to the 1960's and 70's when a collection of influential scientists and designers began to draw the world's attention to the impact human activities were having on our planet. In 1968 James Lovelock, an inventor and scientist from the UK, published the *Gaia Theory* (Lovelock, 2000), in which he proposed that the earth was a self-regulating organism that required a very specific chemical balance in order to maintain the conditions required for life. Through the production of pollution and the creations of other harmful chemicals, Lovelock argued, human actions were threatening this balance.

In 1971 Victor Papanek's book *'Design for the Real World'*, became one of the first to link this thinking with the design of products. Papanek's opening line stated that, "there are professions more harmful than industrial design, but only a few of them." The reason, he argued was that "by creating whole species of permanent garbage to clutter up the landscape, and by choosing materials and processes that pollute the air we breathe, designers have become a dangerous breed" (Papanek and Fuller, 1972). Papanek was highlighting the vital role that designer's play in determining the

environmental impact of our consumption, and challenging them decouple consumption from adverse environmental effects.

The response to this 'call to arms' has been slow, however the intervening years have seen gradual development and legitimisation of environmental design thinking. What began with a small group of radical thinkers, such as Lovelock and Papanek, in the 1960's, was bolstered by the energy crisis of the 1970's, the man made ecological disasters of the 1980's and the increasing awareness of the impacts of global consumerism present today (Knight, 2009; Wotton et al, 2005).

Today environmental impact reduction is a widely researched topic. Authors from design, engineering, management, environmental science, chemistry and marketing backgrounds discuss what it means theoretically and practically, within their disciplines. ISO documents 14006 and 14062 guide the management (ISO, 2002) and process (ISO, 2011) of eco-design implementation, while EU directives and working documents have begun to translate these issues into industrial guidelines that support the environmental improvement of specific products (European Comission, 2009; European Commission, 2005). Eco-design activities can also be guided by a wealth of tools that address each stage of the product development process (Navarro et al., 2005), with the most common, Life Cycle Assessment, being supported by its own ISO standard (ISO, 2006).

While industrial implementation has been far from consistent, leading some authors to describe it as "*stagnating*" (Charter and Clark, 2007) or "*stationary*" (Boks, 2006), momentum is gathering. Large companies such as Philips (Cramer and Stevels, 1997), Siemens (Quella and Ieee Computer, 2001) and Nike (White et al., 2008) paved the way by developing their own internal eco-design business practices and processes, and proving the direct and indirect economic benefits that eco-design can offer (Stevels, 1999). Today most major corporations have undertaken some form of environmental process- or product-driven initiative, with examples from McDonald's re-use of cooking oil to power their delivery trucks (McDonalds Corporation, 2015), through to Marks and Spencer's sustainability focussed 'Plan A' strategy (Marks and Spencer PLC, 2015). As the economic case for environmental design is increasingly uncovered (Lindahl et al., 2014), this appeal widens further, gaining interest from previously disconnect companies.

The basis of this research is an introductory eco-design case study conducted in such a company. The outcomes are seen as a contribution to the growing number of

published case studies available and the ongoing development of knowledge for eco-design practice, leading to environmentally improved product outcomes.

1.3 Research Aims and Objectives

1.3.1 Identifying the Research Aims and Objectives

Industrial eco-design has been described as having a “pilot-project character” (Ammenberg and Sundin, 2005), with many companies struggling to move past the introductory phase (McAloone, 2000; Shelton, 1995). In addition to this, many academically-supported pilot projects have been found to poorly embed the knowledge required to support independent activity following the removal of external support (Hernandez Pardo et al., 2011; O'Rafferty, 2008). These findings are important because of the number of early stage eco-design projects that are supported by an external resource (Brones et al., 2014; Cluzel et al., 2015; Ericson and Frisk, 2000; Pamminger et al., 2007; Pigosso et al., 2013; Prendeville et al., 2011; Schendel and Birkhofer, 2007; UNEP, 2007), and the important role that the academic/industry interaction has played in the development of eco-design (Li et al., 2015).

Within the existing literature two observations have helped define the aims and objectives of this research. The first is that despite the existence of numerous eco-design implementation tools (Dufrene et al., 2013; Le Pochat et al., 2007; Pigosso, 2012), there is a limited focus on the specific requirements and challenges within the introductory phase. The second is that while a large number of eco-design case studies exist, their focus tends to be on the activities involved in undertaking eco-design and not the long term impact of these activities. There are a number of potential reasons for this. Firstly the authors' goal may be in developing and maturing the methodological approach. In this instance knowledge development at the company is important but not the focus. Secondly, it may be difficult to engage companies once the pilot project has been completed. Thirdly, it can be challenging to assess the impact of a particular intervention, determining what has happened from what would have happened. Despite these challenges, failure to adopt a longitudinal approach prevents the long term impacts of these project from being assessed (Ammenberg and Sundin, 2005), ultimately reducing the learning which could improve introductory eco-design projects. With these observations in mind the following section details the research aims and objectives of this work.

1.3.2 The Research Aim

The broad research aim for this work is:

“Investigate how introductory eco-design projects can promote and support ongoing eco-design development within design and manufacturing companies.”

1.3.3 The Research Objectives

To meet this aim the following research objectives were defined:

Objective1: Describe the introductory eco-design context in detail and identify the key opportunities and challenges presented by it.

Objective 2: Taking a longitudinal perspective, assess the impact of introductory eco-design activities in the longer term and their ability to motivate and support ongoing eco-design activity.

Objective 3: Develop and review a process that supports introductory eco-design activities which promote and support ongoing development within design and manufacturing firms.

1.4 The Dissertation Structure

The structure of this dissertation has been developed to meet the objectives and guide the reader through the work conducted in a logical manor. Figure 2 describes how the subsequent sections address the research objectives. It is worth noting that the dissertation structure and the chronological order of the research activities differ from one another. The order of the research activities and the methodology adopted to conduct this research is described in Section 1.5.

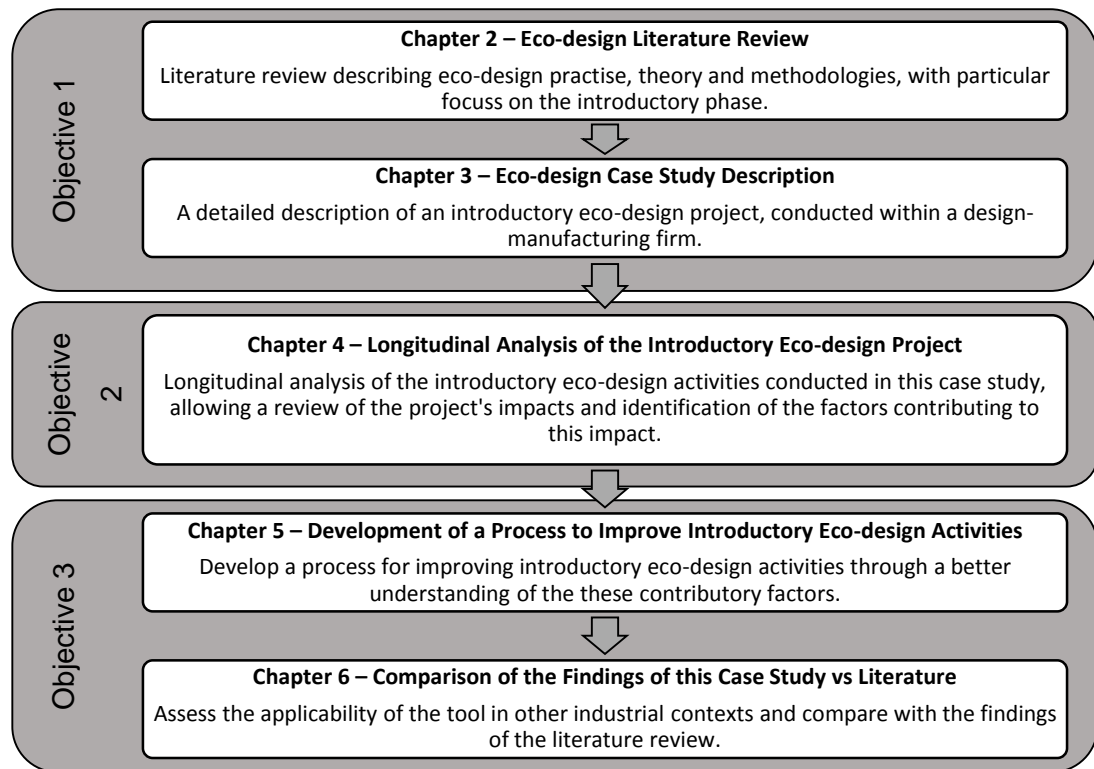


Figure 2: Document Structure Revealing how the Content Meets the Research Objectives

1.5 The Research Structure and Methodological Approach

The research described in this dissertation, adopts an inductive approach (Dudovski, 2011; Thomas, 2006). To explain the methodological approach adopted, the chronological order of the research structure is first described.

1.5.1 The Research Structure

The structure of the dissertation differs to the structure of the research. This has been done to aid the readers understanding and guide them logically through the document. Figure 3 describes the order in which the research activities were conducted and the research outcomes of each activity. As shown the introductory eco-design project provided the research assumption that drove this research project and therefore preceded the literature review.

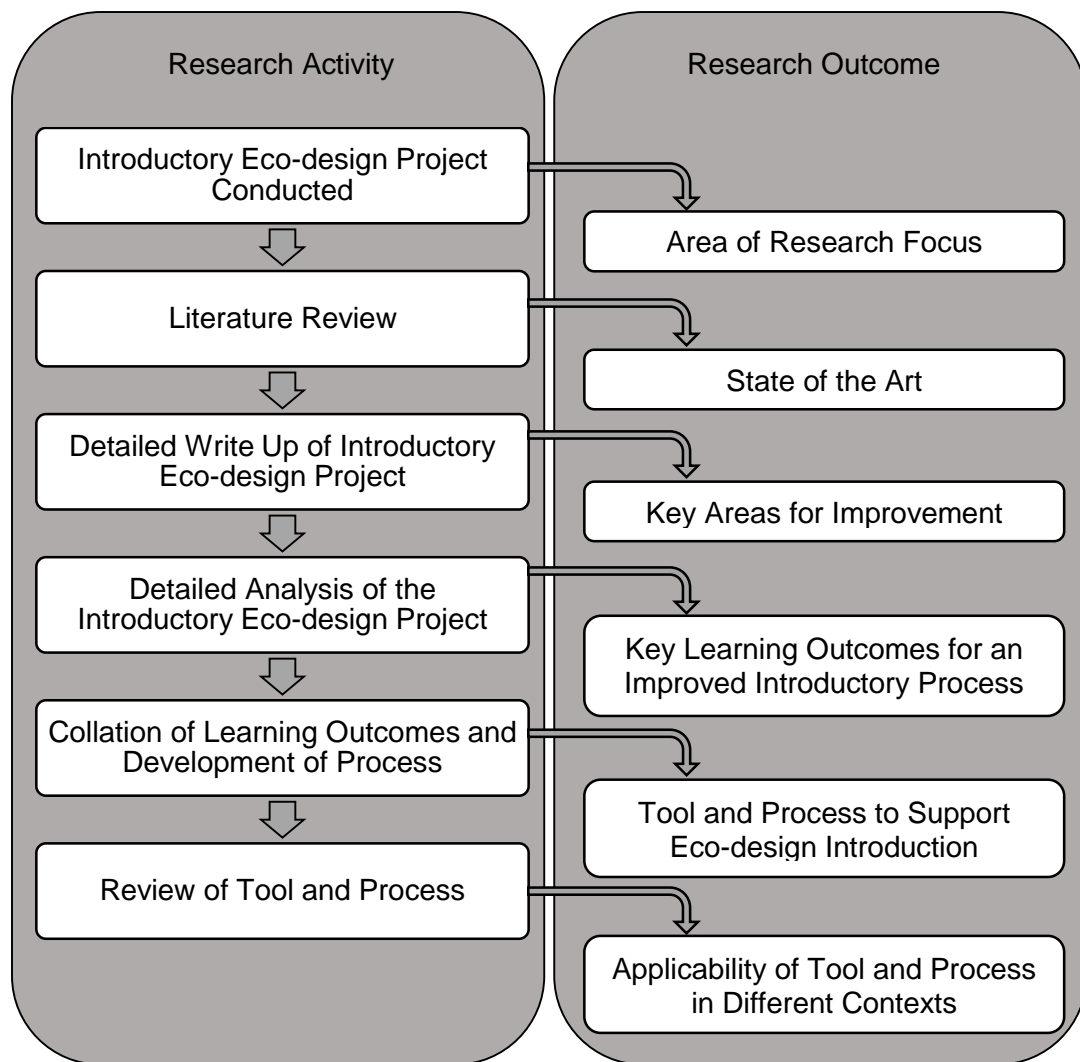


Figure 3: Structure of Research Activities and Outcomes

As described in Figure 3, the area of focus for this research project was identified through the completion of an introductory eco-design project. The author conducted this project and observed its apparent failure to promote and support ongoing eco-design development. The completion of this introductory project provided the overarching premise of the research. A thorough literature review was then used to ensure that the subsequent work and project outcomes were generalised enough to be used in other organisation contexts. In line with this approach and the research objectives and aim, an inductive research methodology was adopted.

1.5.2 Inductive Research

The inductive approach “*begins with detailed observations of the world, which moves towards more abstract generalisations and ideas*” (Neuman, 2005).

In research terms this means that inductive projects do not set out to prove or disprove a hypothesis or theory based on existing knowledge; the deductive approach. Instead these hypotheses are drawn from observations made by the researcher. This is sometimes referred to as a “*bottom up approach to knowing, in which the researcher uses observations to build an abstraction*” (Lodico et al., 2010). As a results of this, the methodological structure of inductive studies tends to be far more fluid to enable the research to adapt as theories begin to form, as described by Thomas (2006).

“The primary purpose of the inductive approach is to allow research findings to emerge from the frequent, dominant, or significant themes inherent in raw data, without the restraints imposed by structured methodologies.”

Rather than adopting a structured research methodology, inductive research projects instead tend to go through three main activities, as shown in Figure 4.



Figure 4: The Three Main Activities Undertaken in an Inductive Research Project

Although sometimes used for quantitative research, the inductive approach is predominantly associated with qualitative data collection. The inductive approach is put into a broader research context by the comparison of quantitative and qualitative methods (Dudovskiy, 2011), shown in Table 1.

	Concepts associated with quantitative methods	Concepts associated with qualitative methods
Type of reasoning	Deduction Objectivity Causation	Induction Subjectivity Meaning
Type of question	Pre-specified Outcome-oriented	Open-ended Process-oriented
Type of analysis	Numerical estimation Statistical inference	Narrative description Constant comparison

Table 1: Contextualising the Inductive Approach through a Comparison of Qualitative and Quantitative Research Methods

1.6 The Research Structure

Reflective of the inductive approach adopted, the research structure is described in Figure 5.

Inductive Research Phase	Research Activity Conducted in this Project
Observation	Literature Review
	Case Study Description
Identification of Patterns	Two Retrospective Case Study Analyses and Findings of Literature Review
	Identification of Key Organisational Characteristics
Development of Theory	Development of an Introductory Eco-design Process
	Assessment of the Introductory Eco-design Process

Figure 5: The Inductive Research Structure within the Context of this Research

Figure 5 shows how the three overarching phases of inductive research have been split into five key research activities. The methodology and structure of this research was adopted to enable the development of knowledge and understanding as the research

activities were conducted and meet the research aims and objectives. A description of each of the research activities is given below.

- 1) A literature review to observe the perspectives of others in this field of research and widen the knowledge and understanding beyond that provided by the single case study.
- 2) A detailed description of the introductory case study conducted by the author and analysis based on the authors overt ethnographical observations.
- 3) A retrospective assessment of the case study achieved through the completion of Standardised Open-Ended interviews (Turner, 2010), analysis of real time project documentation and assessment of subsequent product launches by the Company.
- 4) A second retrospective review of the case study to identify patterns within the data collected and allow the identification of salient company characteristics when introducing eco-design.
- 5) The development of an Introductory Eco-design Process to improve the effectiveness of introductory eco-design projects.
- 6) Assessment of the application of this Process within a broader context, further maturing the theory developed.

1.7 Research Limitations

The theory and tool developed in this research has been drawn from a single case study within a small to medium sized design and manufacturing firm. Assessment of the findings against the literature reviewed has been completed to the help address this limitation, however further work is needed to fully understand the application of tool in other companies or industrial contexts.

2. Literature Review

The first objective of this research is to describe the introductory eco-design context in detail and identify the key opportunities and challenges presented by it. This objective has been met through the completion of two activities; a literature review that describes the state of the art and the detailed write up of an introductory eco-design case study (Chapter 3).

The literature reviewed has been grouped under three headings: defining eco-design, introducing eco-design and implementing eco-design. The first defines industrial eco-design within the context of this research to ensure clarity and define the parameters of the research project. The second examines existing knowledge related to the nascent stage eco-design development and identifies activities that promote movement beyond this phase. The third section describes existing methodologies for the implementation and management of eco-design through continuous improvement.

2.1 Defining Eco-design

Eco-design, also known as environmental product design or Design for Environment (DfE) is defined in ISO standard as *“the integration of environmental aspects into product design and development, with the aim of reducing adverse environmental impacts throughout a product's life cycle”* (ISO, 2011)

As the definition suggests, eco-design is both process based, involving the incorporation of environmental considerations within design decision making, and product based, involving physical adaptations to a product that reduce its environmental impacts (Ammenbergh and Sundin, 2005). The challenge in researching such a topic comes from the inherent variability embedded within this definition. Firstly the *“product design and development”* process will depend upon the product being made and the organisation making it (Deutz et al., 2013). Secondly, the *“integration of environmental aspects”* must be achieved across the multi-disciplinary product development process (White et al., 2008). Finally, there are the widely different biological and technical mechanisms by which products impact the environment; introducing variability to the definition of what constitutes an eco-design activity. The result is a patchwork of eco-design definitions, examples, successes, failures, priorities, approaches and methodologies, that lack systematic agreement on how eco-design is to be achieved (Pigosso et al., 2013).

To guide the reader through this complex academic and industrial background, the first section of this literature review aims to fully define eco-design in the context of this research. A definition is developed through a discussion of the reviewed literature. This process enables a broad discussion of eco-design whilst enabling the scope of this research to be defined.

2.1.1 Eco-design integrates Environmental Aspects into the Traditional Design Process

As implied by the use of the word “*integration*” within the ISO definition, eco-design is viewed as a process of environmentally focussed adaptations to an existing design process or product. Describing eco-design in this way helps scope the aims and activities that it encompasses.

The first point of note is that eco-design is environmentally-focussed and does not extend to include the social impacts of product development covered by sustainable design (Howarth and Hadfield, 2006).

In his exploration of eco-innovation O’Hare (2010) distinguishes between five levels of environmentally inclusive design:

- 1) Design for Environment (DfE) - integrates environmental considerations into product design but focuses on one phase of the product life cycle;
- 2) Eco-design - broadens DfE to consider the entire product life cycle;
- 3) Eco-innovation – extends eco-design into the early stages of innovation;
- 4) Environmentally Conscious Design – an umbrella term for DfE, eco-design and eco-innovation;
- 5) Sustainable Design - any form of DfE or Eco-Design that considers social and economic aspects of sustainability as well as the environmental aspects. (O’Hare 2010).

While the inclusion of social considerations is a clear difference between sustainable and eco-design, these ideas are by no means distinct. Authors such as Karlsson and Luttrupp (2009) make this point clearly by defining eco-design within the context of sustainable development.

“Eco-Design is an aspect of design, a new smart design for the future in line with the Bruntland report statement that a sustainable future fulfils today’s needs without jeopardizing future generations’ possibilities to reach their own goals” (Karlsson and Luttrupp, 2006)

This is an important definition because sustainable development is defined by its triple-bottom-line approach, which seeks to balance economic, ecological and social aspects within production (Gmelin and Seuring, 2014). Viewing eco-design within this broader context ensures that the economic or profit motive is not discarded in the face of the environmental challenge, as shown in Figure 6.

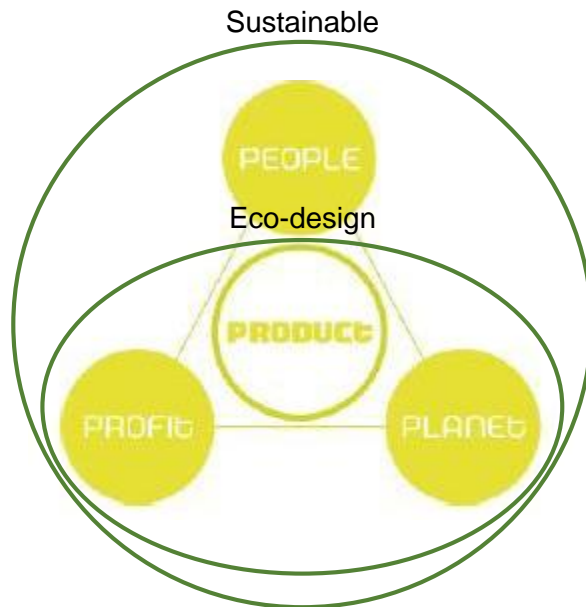


Figure 6: Eco-design defined within the Broader Context of Sustainable Design. Figure is adapted for this Thesis from (Clark et al., 2009)

Johansson (2002) takes this further to ensure that more aspects of traditional design are included within eco-design.

“The term Eco-Design refers to actions taken in product development aimed at minimising a product’s environmental impact during its whole life cycle, without compromising other essential product criteria such as performance and cost.” (Johansson, 2002)

The definition given by Johansson is important when viewing eco-design as an integration of environmental aspects within an existing design process, because it highlights that environmental criteria are additional rather than substitutionary. The inherent challenge presented by the integration of this additional criteria, is visually described by Luttrupp and Lagerstedt (2004), as shown in Figure 7.

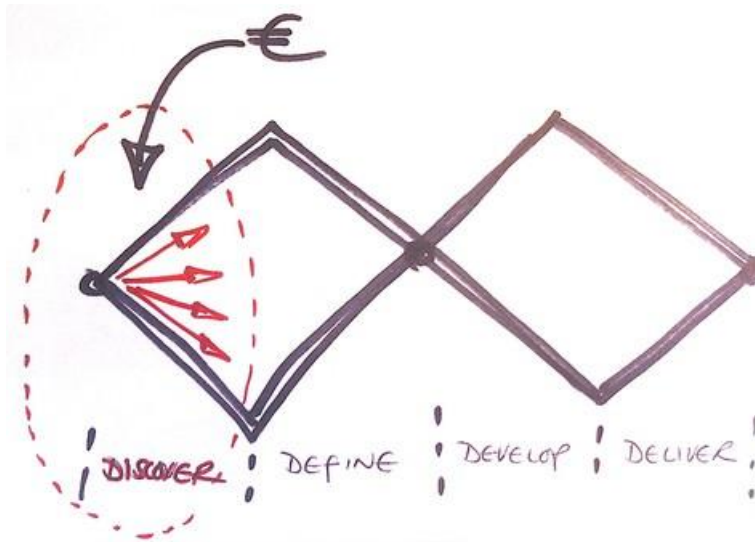


Figure 8: The Double Diamond Design Process (Wilson, 2012)

In their book on the Engineering Design process (Pahl et al., 1996) offer the 'Systematic Approach', which can be broadly seen to describe a series of convergent and divergent activities which take place over four key design phases; planning and task clarification, conceptual design, embodiment design and detail design, which lead you from discovery to delivery. Each of these phases is described in detail and summarised in Figure 9. In the Systematic Approach we can see activities such as market analysis are included as part of the early stages of design definition.

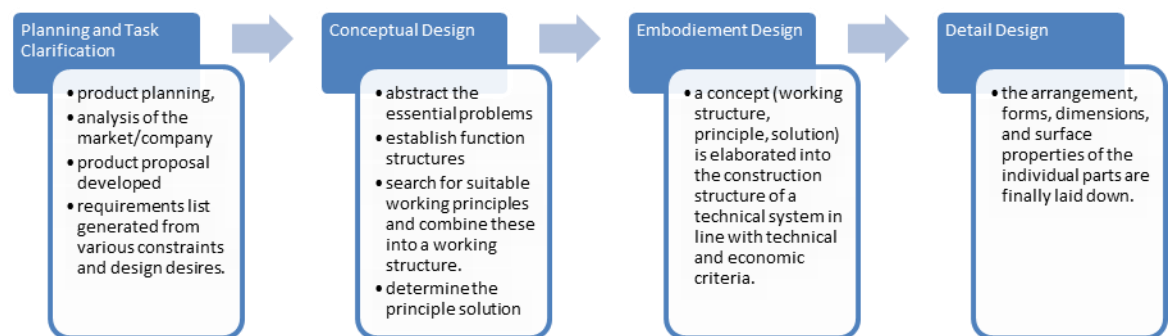


Figure 9: Pahl et al's (1996) Systematic Approach as represented in (Zeng et al., 2003)

The Total Design Process developed by Pugh (1991) and described in Figure 10, broadens the design process still further with the aim of including all the activities required to take a product to market. Within this model the core design activities are shown as a central process, with the double headed arrows between each representing the often non-linear nature of design development. Each stage of this process requires specific inputs in order to progress and it is these inputs that may encourage a return to a previous stage; for example where new information found during detailed design

triggers the idea for a new concept. These inputs are represented by the arrows down either side of the core activities.

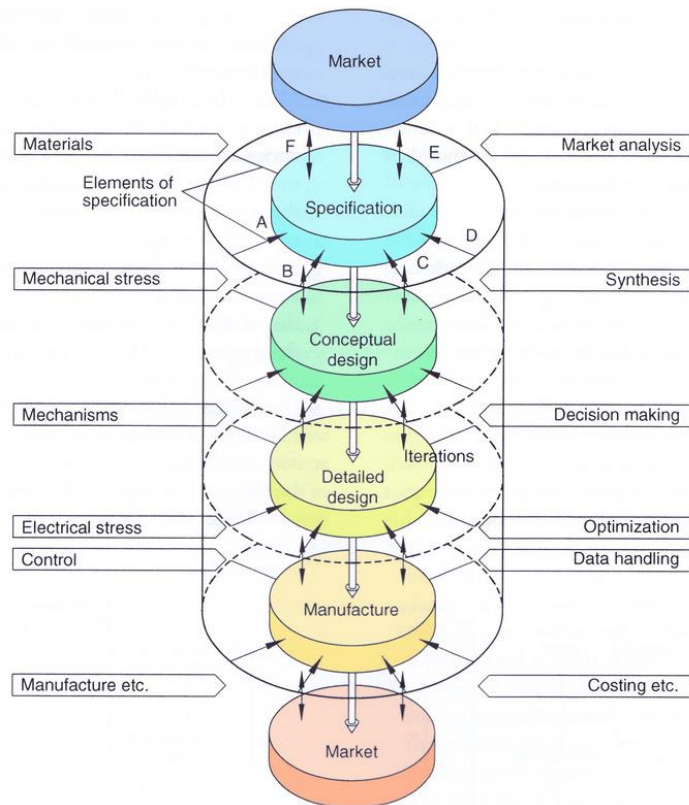


Figure 10: The Total Design Process (Pugh, 1991)

Within the context of this research Pugh's Total Design Process is favoured due to its holistic, cross-disciplinary representation of the design delivery process that is more akin to what others term the value chain. A product's value chain is defined as the series of activities required to deliver a product to a market (Porter, 2008). The broader scope of the value chain concept is described by the Centre on Globalization Governance and Competitiveness (GVCI, 2014). It is worth noting that the activities included in the value chain are distinct from the environmental product life cycle in that they stop at the point of customer use.

“The value chain describes the full range of activities that firms and workers do to bring a product from its conception to its end [customer] use. This includes activities such as design, production, marketing, distribution and support to the final consumer. The activities that comprise a value chain can be contained within a single firm or divided among different firms. Value chain activities can produce goods or services, and can be contained within a single geographical location or spread over wider areas.” (GVCI, 2014)

What becomes clear is that the product solution derives from a series of decisions informed by the inputs and perspectives from a cross functional team. Each phase of this development is intrinsically linked and each input has repercussions throughout the process. White et al (2008) represent this idea diagrammatically as duplicated in Figure 11.

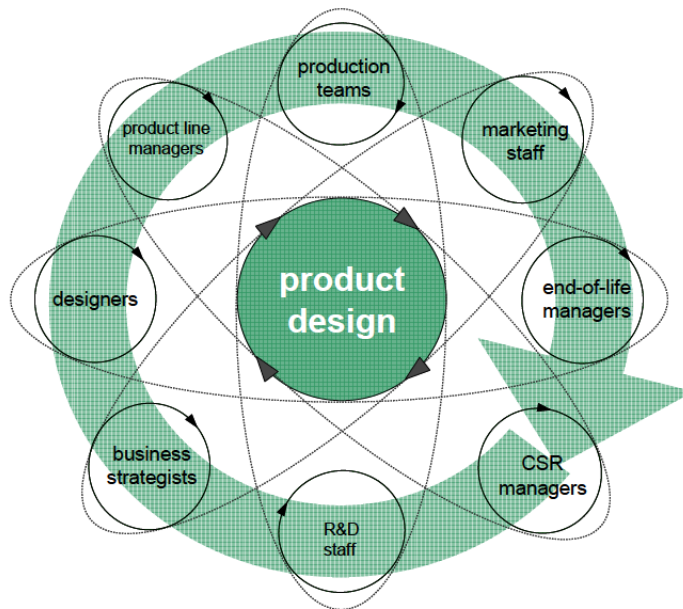


Figure 11: The Multi-disciplinary Nature of the Product Design (White et al., 2008)

In this section the ‘traditional’ product design and development process has been defined as a series of convergent and divergent activities that move from a need to a solution. The development of this solution results from the activities and perspectives of a cross-disciplinary team that moves beyond traditional design activities to include the full product value chain. These ideas are important to the discussion of eco-design because they describe the breadth of activities and disciplines within which eco-design must integrate. In their report on the integration of sustainable design, White et al (2008) describe this in terms of “capacity building” as well as product development.

“New organisational intelligence is needed because sustainability introduces a range of factors into organisations that lie outside the expertise of people traditionally called designers. As a result, sustainable design is not just about making better products, but about developing the capacity of the organisation to make better products. It means increasing the sustainability intelligence of an organisation and making sustainability a systematic part of the design process. It is about re-envisioning design, not just following a marketing mega-trend, since approaching sustainability in a one-off manner runs the risk of missing opportunities and of sustainability-related consumer boycotts.”
(White et al., 2008)

2.1.3 Eco-design is a Process of Organisational Learning

Identifying eco-design as a process of organisational learning has led many authors to trace and define the stages of the maturation process (Brezet et al., 1997; McAloone, 2000; O'Hare, 2010; Pigosso, 2012). In her extensive literature review on the subject Pigosso (2012) describes ten “eco-design maturity models” that describe this maturation process. These models have been reviewed for this research, allowing common maturation metrics to be identified, as shown in Table 2. High performance against each of these metrics can be seen to characterise a mature eco-design organisation.

Characteristics of a Mature Eco-design Organisation	
Metric	Source
Environmental Knowledge	(Boks and Stevels, 2007; Charter and Tischner, 2001; McAloone, 2000)
Cross-departmental Engagement	(Charter and Tischner, 2001; McAloone, 2000; Murillo-Luna et al., 2011)
Strategic Management Support	(Alakeson and Sherwin, 2004; Charter and Tischner, 2001; Pascual et al., 2003; Shelton, 1995; van Someren, 1995)
Vision for Environmental Improvements	(Alakeson and Sherwin, 2004; McAloone, 2000; Murillo-Luna et al., 2011; Shelton, 1995; van Someren, 1995)
Environmental Measurement Techniques	(de Caluwe, 2004; Murillo-Luna et al., 2011; Pascual et al., 2003)
Application of Eco-design Tools	(Boks and Stevels, 2007; de Caluwe, 2004; McAloone, 2000; Pascual et al., 2003)
Commercial Impact of Design Projects	(Pascual et al., 2003; Shelton, 1995)
Location and Timing of Environmental Design Decisions	(Charter and Tischner, 2001; McAloone, 2000; Murillo-Luna et al., 2011)

Table 2: Summary of the Metrics Used to Determine A Company's Eco-design Maturity

2.1.4 Eco-design is Primarily Product Development Focussed

Eco-design is also viewed as a process that supports the development and delivery of environmentally improved products and is therefore distinct from the corporate level

environmental initiatives taken to improve an *organisations* environmental performance. The foundation of this product focussed thinking is the concept of the environmental product life cycle. A product's environmental lifecycle incorporates all the activities related to its creation, use and disposal. As such, although the concept is centred on the product, it does not limit environmental improvements to the physical attributes that product. Evidently this understanding of eco-design incorporates both process and product activities and therefore extends to the management activities that oversee both. This thinking is reflected in Pigosso and Sousa (2011) definition of eco-design as a management activity that drives product improvements.

“Eco-design is a proactive management approach which directs product development towards environmental-impact reduction along the product life cycle” (Pigosso and Sousa, 2011)

The most common methodology for the calculation of these impacts along the product development lifecycle is the life cycle assessment, or LCA, approach. The LCA technique was developed to improve industry's understanding of how products impact the environment and support environmental decision making (Guinée et al., 2010). It achieves this by calculating the environmental impacts “throughout a product life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal” (ISO, 2006). The typical environmental lifecycle of a product and the environmental inputs and outputs associated with this lifecycle, are shown in Figure 12.

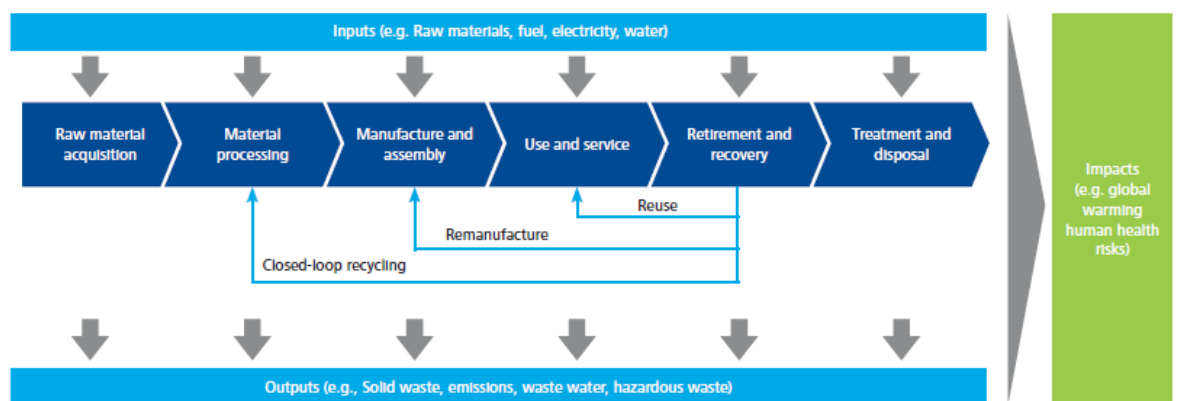


Figure 12: The Product Environmental Lifecycle, adapted from ISO 14040:2006 by (Foster, 2012)

Taking this full lifecycle perspective (which is far broader than the typical manufacturing and use phase perspective of designers) offers some clear advantages when assessing a product's environmental impact. Firstly it incorporates all the relevant actions required to produce, use and dispose of a product, revealing the full

environmental burden. Secondly, it exposes the transfer of impacts between lifecycle stages, highlighting where an environmental improvement in one lifecycle phase causes a disproportionate increase in the impacts of another (Guinée et al., 2002).

The ISO standard governing the LCA process describes four phases in the LCA process. Unless stated otherwise the description provided here is adapted from this standard (ISO, 2006).

- 1) Goal and Scope Definition: definition of why the study is taking place, the intended audience and the “breadth, depth and detail” required to meet the desired goals. The scope of an LCA will describe the functions to be included and omitted, and the type of environmental impacts (impact categories) that will be documented.
- 2) Inventory Analysis: the data collection phase, aimed at calculating the environmental inputs and outputs of the functions and lifecycle stages included in the study. Inputs include energy, raw materials and water; while outputs include physical waste and emissions to air, water and soil. The inventory phase is the most time consuming stage of the LCA process, however this intensity is proportional to the scope of the study.
- 3) Impact Assessment: attempts to “evaluate” and “understand” the significance of the environmental impacts identified in the inventory analysis. It achieves this by translating the resources and releases calculated in the inventory analysis, into potential environmental and human health impacts, such as global warming potential, acidification and eutrophication (SAIC, 2006). The impact assessment introduces subjectivity to the process as different authors, and databases, translate the impact of resource use and emissions differently.
- 4) Interpretation: the assessment of the results obtained against the goals defined, allowing conclusions and recommendations to be made.

Due to the complexity of the product systems and the various ways in which they interact with biological systems, the LCA process is often deemed to be too data and resource intensive (Millet et al., 2007). To allow this process to be included within the time restrained design development process, simplification and streamlining is common (Arena et al., 2013).

A common simplification is to conduct a Life Cycle Inventory Study (LCI) rather than a full LCA (ISO, 2006). An LCI study omits the impact assessment phase, removing the need for translation data, whilst also preventing the introduction of subjectivity to the

process. The results of an LCI will quantify the inputs and outputs of a system, but do not identify *how* these resource flows impact the environment.

Data requirements can be further reduced by carefully aligning the goal and scope of the study. This may involve omitting life cycle phases or resource flows, based on assumption relating to their relative contribution. While this has potential for error and has obvious impacts on the level of detail achieved, the resource it saves enables lifecycle thinking and design decision support, without a disproportionate increase in a product's time-to-market.

2.1.5 A Definition of Eco-design

The literature reviewed here has identified four aspects of eco- and traditional-design that help develop a definition within the context of this research. Each of these aspects is described below, followed by the definition.

- Eco-design integrates environmental aspects into the traditional product development process.
- The traditional product development process is a multi-disciplinary process that can be conducted by individuals or multiple organisations. Every person in this product development process has a perspective and influence over the product design outcome.
- The integration of eco-design is required throughout the product development organisation (individual or multi-organisational). The scale of the organisation is therefore inherently linked to the scale of the challenge when integrating eco-design, due to the increasing scale of change required.
- Eco-design is primarily product focussed and driven by a life cycle approach as such it does not inherently focus on the activities of the organisation conducting it.

As a result, eco-design has been defined as a product-focussed process of continuous improvement that sees the integration of environmental aspects into the multi-disciplinary, multi-organisational product development process. While the aim of eco-design is to reduce environmental impacts throughout the products lifecycle, eco-design itself can be seen as a product development learning process that moves from complete naivety to full maturity.

2.2 Introducing Eco-design

As previously described, many companies struggle to move past the introductory phase of eco-design, leading authors to describe it as having a 'pilot project nature' (Ammenberg and Sundin, 2005). Evidently, due to the difficulty companies' face in progressing past the introductory stage of eco-design, the organisational context presents some significant challenges. To understand these challenges the following section draws together research that describes companies in the nascent stage of eco-design development, allowing common characteristics to be identified

2.2.1 Characterising Companies in the Nascent Stage of Eco-design Development

To understand existing knowledge relating to the organisational context during the nascent stage of eco-design development, Table 3 collates early stage company descriptions from each of the other authors' maturity models listed by Pigosso (2012). Table 3 contains the words of the primary author, rather than those of Pigosso, except in the case of Charter (2001).

Title of first stage	Description of first stage in maturity models	Source
Defensive	Ecological management is ad hoc and not regarded as an important issue in the company's strategy, or in the best case compliance with regulations is formulated as the highest goal. In short environment issues are an external problem. Technical measures dominate over organisational measures.	Somerén (van Someren, 1995)
Initial/Sustained Motivation	Catalysed by a single external demand or force, such as legislation or competition. Initial activities may be contained within the design process and focussed on single issue improvements to their design, with limited management contact.	(McAloone, 2000)
Ignorance and Starter in Eco-design	Ignorance – Company is not familiar with eco-design issues. Starter – Environmental manager is in the process of selling internal business benefits and opportunities with the adoption of eco-design in the company.	Charter (2001) in Pigosso (2012)
Single Issue	Activities address a specific sustainability issue in reaction to a single external environmental pressure. No systematic way of addressing wider environmental issues and a lack of strategic focus.	(Alakeson and Sherwin, 2004)
Stages 0 and 1	Stage 0 – Development department delivers products without attention to their environmental consequences;	(de Caluwe,

	<p>no programs or tools exist to address this issue.</p> <p>Stage 1 – Environmental issues are taken into account only incidentally and mainly driven by individual initiatives. Environmental risks to the business are not identified or assessed. There are first signs of methods and tools; remedial features are introduced to correct unwanted environmental effects.</p>	2004)
Groups 5 and 6	<p>Group 6 – Companies do not use eco-design nor does it publish any environmental product claims.</p> <p>Group 5 – Company markets their use of eco-design but does not publicise specific details and is unlikely to spend significant resource on eco-design.</p>	(Pascual et al., 2003)
Relatively Ignorant	Company still needs to be introduced and/or convinced concerning product-related environmental threats and opportunities. Company may have conducted an initial project but that will involve a single department.	(Boks and Stevels, 2007)
Passive Strategy	Environmental objectives not pursued and firm dedicates little to no resources to environmental protection. Firm does not adopt any technical or organisational protection measures, does not plan to obtain environmental certifications and does not have any employees dealing with environmental matters.	(Murillo-Luna et al., 2011)
Maturity Level 0	<p>Evolution Level – no eco-design experience and no application of eco-design practices within product development. No understanding of the environmental issues related to products or the benefits offered by eco-design.</p> <p>Innovation Level – No environmental improvement has been achieved as eco-design projects have not been undertaken.</p>	(Pigosso, 2012)

Table 3: Characteristics of Companies in the Nascent Stage of Eco-design Development

Summarising these extracts provides the following characteristics of companies in the nascent stage of eco-design development:

- 1) Low knowledge about environmental issues with no experience of achieving environmental improvements.
- 2) Limited knowledge of the tools available to support eco-design and no experience of using them within design development.
- 3) Eco-design is typically viewed as a technical or product development challenge that is not organisationally or strategically consequential.
- 4) Limited or ad hoc management with a low commitment of resource.
- 5) Typically driven by legislative compliance or competitive survival.

- 6) Limited understanding of the business opportunities or risks posed by environmental development.
- 7) Low motivation towards environmentally improved product development.

What these characteristics reveal is a challenging organisational background against which eco-design must establish a foothold. The limited knowledge, vision and motivation present during the nascent stage must be addressed during introductory activities if ongoing development is to be achieved.

2.2.2 The Impact of Existing Company Characteristics when Introducing Eco-design

Many authors discuss the impact of existing company characteristics on the success of introducing eco-design

Salomone et al's (2013) collation of Product Oriented Management Systems (POEMS – described in detail in the next section) found that although the use of a POEMS process accelerates the implementation of eco-design activities, the organisational context, had a far greater impact on the pace of change.

"Organisations implementing POEMS report greater effects on environmental improvements than others but the real environmental improvement options are limited by the context in which companies operate (e.g. demand for green products, legislation/fiscal stimulus, pressure from environmental movements, etc)" (Salomone et al., 2013).

Ammenberg and Sundin (2005) identify four levels at which organisational characteristics impact the implementation of a POEMS approach and the outcomes it achieves, as shown in Figure 13.

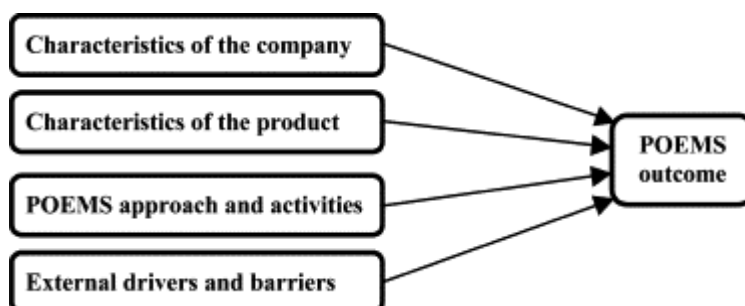


Figure 13: The four levels of factors influencing the extent to which Environmental Management and Design for Environment factors are integrated as identified by (Ammenberg and Sundin, 2005)

The characteristics within each level are listed to provide “a general orientation to factors of importance that may be useful when analysing companies’ possibilities and motives to engage in POEMS activities” (Ammenberg and Sundin, 2005).

Level 1 - Characteristics of the company

- Availability of human and economic resources
- Company structures, systems, cultures and attitudes
- Eco-design motivation, knowledge and experience and the availability and quality of new knowledge and experience.

Level 2 – Characteristics of the product

- The products potential for environmental improvements and the extent to which environmental considerations were included in the early stages of product development
- The technical requirements, customer needs and the extent to which the customer is willing to pay for environmental improvements
- External product properties (aesthetics, functionality, ergonomics etc).
- Internal product properties (strength, durability etc)
- Product design properties (materials, surface, form structure etc).

Level 3 – POEMS approach and activities

- Extent to which environmental criteria are integrated into the product development process
- Priority given to environmental criteria
- Use of environmental checkpoints, reviews and milestones
- The development and use of company specific design principles, rules and standards and their complimentary application, together with support tools.
- Extent to which eco-design is performed by cross-functional teams

- The level of support provided through education and training and environmental experts.

Level 4 - External drivers and activities

- Supply chain stakeholders
- Auditors (who assess the approval of environmental management systems), authorities and politicians
- Banks, insurance companies and shareholders
- Competitors and the media.
- The extent to which external incentives exist; economic and legislative
- The consistency of influential actors.

These findings are corroborated by other authors such as Boks and Stevels (2007), who find that “*company-specific factors determine to a large extent the appropriateness and acceptance of eco-design strategies.*” In their study of eco-design in the electronics industry Boks and Stevels (2007) identify three characteristic groups that impact eco-design appropriateness and acceptance; strategic, organisational and product development characteristics. These are described as:

Strategic issues – company strategy, programmes and priority, supply chain items, design strategy

Organisational issues – role of senior management, integration and involvement of business functions

Development process issues – idea generation, conceptual design, detailed design and market launch

Shelton (1995) suggests that an eco-design team should first understand the company's:

- Product portfolio
- Competitive environment
- Technology management issues – state-of-the-art, company position, cycle time

- Environmental management issues – sophistication, prior experience with environmental issues, management mind-set
- Centres of power – who is really in charge and what are the unwritten rules of the game

What the authors are identifying is that the existing characteristics of an organisation can support or challenge eco-design implementation. While some companies may be able to draw upon existing and opportune resources that promote eco-design, others may find that their very structure counters their efforts. What is clear is that dependent upon this existing environment, very different eco-design activities will be needed to progress development.

2.2.3 Advancing beyond Introductory Eco-design

Despite the inherent variability some authors do offer recommendations for moving past the introductory stage. The following section summarises the advice and recommendations given.

McAloone (2000) highlights that the motivation for eco-design changes must be sustained by an internal or external driver and suggests that while early stage efforts may be contained within the design or engineering department, further progress can only be made through the engagement and support of top management. He also suggests that the gradual development of tools and techniques that support eco-design activities is needed to aid consistent development.

Charter (2001) discusses the use of an environmental manager in the early stages whose role is to sell the business benefits and opportunities of eco-design internally. Once the business understands the commercial opportunity, the development of a “green” pilot project is then promoted to help focus efforts and move beyond the early stages.

Alakeson et al (2004) suggests that integrated tools are important in the early stages, as the addition of increased complexity during this fragile stage is likely to gain little traction. They also highlight the importance of involving a cross-functional team that include corporate social responsibility (CSR) representatives to help identify new opportunities beyond existing markets. Again the use of a pilot project is promoted.

Boks and Stevels (2007) make the observation that companies who have been successful in moving past the first stage of eco-design are the ones that have “picked

the low hanging fruit” as a focus for early eco-design efforts. The point they are making is that focussing initial efforts on easily achieved, or low risk improvements, allows a company to experience successful eco-design in the early stages when motivation is so critical.

Pigosso (2012) identifies the importance of three activities aimed at promoting motivation towards eco-design. These include the identification of the internal and external drivers for eco-design, the development of a benchmarking study and the compilation of product-related environmental legal issues and standards.

Shelton (1995) describes two types of introductory eco-design activities; corporate-oriented and product-oriented. Corporately he promotes the importance of understanding the drivers for eco-design but expands this idea to include potential threats and risks. In essence Shelton describes an environmental Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis (Hill and Westbrook, 1997). This analysis should be conducted by a short-lived, cross-functional and cross-business design for environment (DFE) group, whose job it is to define the business case for eco-design and identify key development projects. Shelton stresses the importance of the temporary nature of this team and the need for those involved to return to their original function to avoid environmental efforts being isolated from core product development activities and integrate learning.

Within product development Shelton also promotes the use of a pilot project and urges that companies “start small” but maintain a long term focus to “expand incrementally”. He adds that the process of eco-design should carefully align with the company culture, organisational culture and design drivers as opposed to forcing its way in.

Following the completion of a successful eco-design pilot project, all of these authors highlight the importance of communicating and integrating this learning more widely throughout a business. Corporate communication, education, training and follow up product development activities are all identified as potential ways of achieving this.

Collating these recommendations identifies the following features needed to sustain eco-design past the pilot stage:

- 1) Sustained internal or external drivers;
- 2) The engagement and support of senior management;
- 3) Cross-departmental engagement;
- 4) Integrated tools and techniques that support eco-design activities;

- 5) An environmental manager who promotes eco-design internally;
- 6) Eco-design improvements that have been achieved through the completion of a pilot project;
- 7) An understanding of the company's eco-design position relative to their competition;
- 8) A cross-departmental understanding of the outcomes of early-stage eco-design activities.

What is striking about the list shown here is the commitment required from a company to support each of them; hiring a new manager is a significant outlay for a company, developing integrated tools requires significant learning and potential alteration to the product development process. The nascent stage of eco-design has been defined as one where companies often view eco-design as a technical issue and lack motivation towards eco-design, resulting in a low commitment of resource. Comparing the nascent characteristics with the recommended features identifies a gap in the literature that looks at the very challenging requirements of this early stage.

Several authors have developed approaches that support the long term adoption of eco-design, as these inherently include the introductory phase the following section provides a description of the most salient tools found in existing literature. Each tool is described as well as the context of its application.

2.3 Implementing Eco-design

Despite a wealth of knowledge design tools that support environmental product design (Navarro et al., 2005), the literature has identified a gap between the characteristics of companies in the nascent stage and the recommendations provided to advance past it. Throughout literature many authors have developed methodologies that support eco-design implementation through a process of continuous improvement. They are included here as their focus inherently includes the introductory phase and their examination is therefore seen to provide relevant learning outcomes for this research project.

2.3.1 Product Oriented Environmental Management Systems (POEMS)

POEMS are defined by Ammenberg and Sundin (2005) as “an environmental management system with a special focus on the continuous improvement of a product's eco-efficiency (ecological and economic) along its life cycle.” Other authors offer more organisationally structural terms describing it as “an approach for organising and operating a firm in such a way that improving the environmental performance of its

products becomes an integrated part of operations and strategy” (De Bakker et al., 2002). The overarching aim of any POEMS is to encourage a structured environmental management approach that is underpinned by a lifecycle approach, and therefore incorporates product development activities as well as production process (Salomone et al., 2013). Incorporating eco-design and management activities is seen to encourage a better management of resources and a more systematic and consistent approach to eco-design that helps move past the current “pilot project” nature of many eco-design projects (Ammenberg and Sundin, 2005).

Despite there being no standardised structure for POEMS, some authors have attempted to collate and summarise existing POEMS examples, enabling the identification of key steps (Ammenberg and Sundin, 2005; Ardente et al., 2006).

Ammenberg and Sundin (2005) review and summarise the key stages of five different POEMS with a focus on the first application of this methodology. As all five of the methodologies reviewed are based on the Deming cycle (or the Plan-Do-Check-Act cycle) (Deming, 1986) the authors are able to summarise the stages of each into one model, as shown in Figure 14.

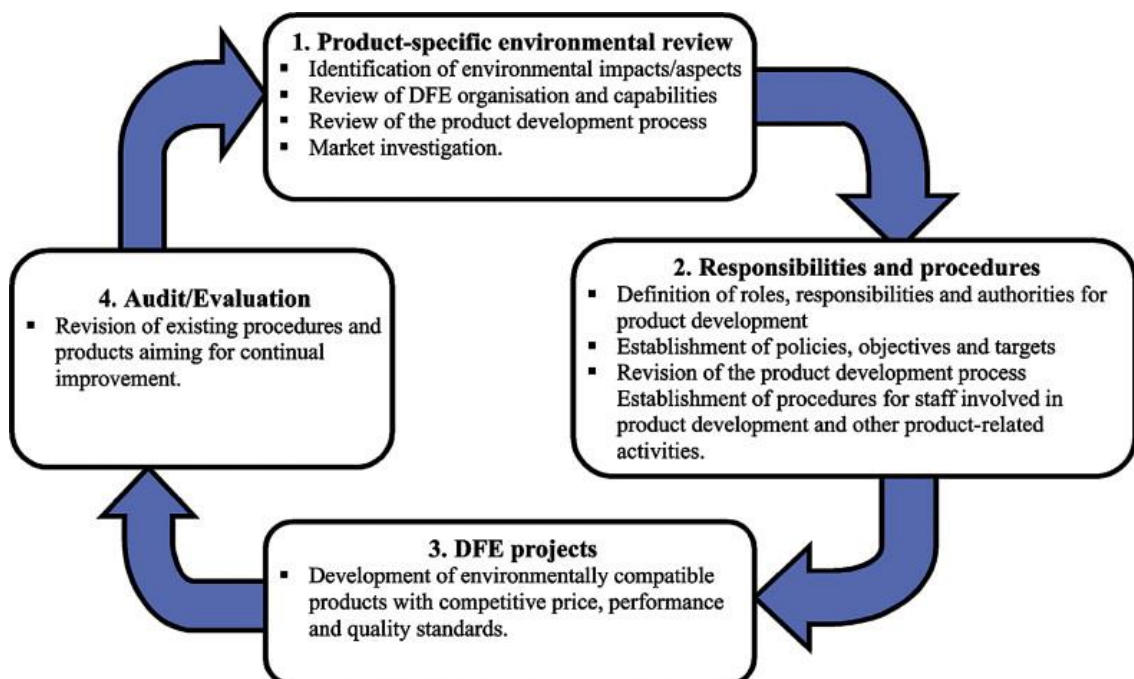


Figure 14: Summary of the Stages Described in Five Different Product Oriented Environmental Management Systems (Ammenberg and Sundin, 2005)

Step 1 includes the completion of an environmental assessment that defines the product’s environmental profile, from this environmental targets are defined. This stage also includes an organisational assessment, to identify the company’s capabilities and

weaknesses when addressing eco-design activities. These assessments should also produce information on existing and future market requirements and customer needs, whilst also identifying existing legal requirements.

Step 2 focuses on the management of environmental product activities by defining the responsibilities, resources and procedures needed to undertake the product development process. The authors reiterate several points summarised in the previous section such as the importance of management support during this phase and an alignment between the goals and activities of the eco-design project and the existing “corporate visions, strategies and policies”.

In step 3 eco-design projects are undertaken using the information gained in step 1 and the processes defined in step 2. This stage needs the involvement of motivated, competent staff whose knowledge is complimentary to one another. To increase the chances of success the environmental improvements must be achieved without impacting the standard time, cost and quality requirements of the company.

The final step is to evaluate and audit the activities undertaken. The findings of this stage are used to improve the next cycle and encourage a continuous improvement process.

In their review of the Dutch government funded 'Stimulating Product Oriented Environmental Management' Incentive (PMZ) Programme, Rocha and Silvester (2001) compare the POEMS activities undertaken by 10 participating companies before, during and one year after their involvement. One year after the removal of external support the authors found that 31% of the POEMS activities were being performed in a continuous way, up from only 6%. Interestingly of the total number of activities identified, 59% began after the completion of the PMZ programme. Only 6% of the activities started during the PMZ programme had continued, however the authors found that this tended to describe a shift from the strategic and managerial activities involved in setting up an organisational framework for POEMS, to the operational activities required to perform them (Rocha and Silvester, 2001). Clearly the success of the POEMS approach was found to vary greatly. As previously explained this was found to be largely linked to the existing business environment within which the POEMS activities were being conducted. The limited success of POEMS within SME's (Salomone et al., 2013) exemplifies this fact. POEMS is by its very nature designed to alter the focus of Environmental Management Systems towards product related impacts (Ardente et al., 2006). SME's are less likely to operate in accordance with

structured management systems, tending as they do to focus on value-adding activities rather than strategic planning and management (McAdam and Reid, 2001; Oxborrow and Brindley, 2013).

The POEMS approach has been found to support eco-design implementation where the activities align closely with the existing characteristics of the company. Companies in the nascent stage of eco-design are typically characterised by a low understanding of eco-design, a lack motivation towards eco-improved product outcomes and as such, a low resources availability for undertaking eco-design activities. Although the POEMS approach offers a systematic and structured approach to eco-design implementation, it offers little guidance to those working to overcome these characteristics of the nascent stage.

2.3.2 The Access-Bridge-Create-Diffuse (A-B-C-D) Framework

The A-B-C-D Framework developed by White et al (2008) takes a different methodological approach, as it is drawn from the observation of companies who have successfully developed their “sustainable design intelligence”. The intelligence reflects a company’s ability to:

- 1) Assess the social and environmental impacts of products and production and evaluate their organisational capacity to address them.
- 2) Bridge the right functions and connect the right people to ensure valuable and embedded change occurs.
- 3) Create projects that enable internal and external exploration and learning about product sustainability.
- 4) Diffuse learning throughout an organisation and ensure the right people have the right information to support better decision making in the future and create accountability for product outcomes.

To help characterise these activities the four case studies provided by White et al (2010) are summarised in Table 4.

A-B-C-D Phase	Case Study		
	Nike	Herman Miller	Clorox
Assess	Lifecycle assessment of product impacts	Launch of a Design for Environment	Business assessment to

	and company activities. Development of new monitoring tools.	(DfE) team to lead product redesign. Assessment of recycled materials potential and catalogue of every material in every product.	identify “natural” cleaning products as an emerging market mega-trend. Review of business units and functions and identification of existing technical expertise and gaps in the capacity of the organisation to utilise this expertise.
Bridge	Creation of the Considered Design Team to serve as a conduit for product sustainability ideas, goals and lessons.	Development of an interdisciplinary discovery team tasked with exploring the influence and required involvement from different functional operations.	Development of a team of staff with proven knowledge, who worked closely with suppliers and procurement to develop a new product line. Development of an Eco Office to coordinate sustainability initiatives towards business growth.
Create	Pilot projects conducted by together proven talent from across the business.	A series of pilot projects concentrated on various aspects of eco-design. Development of a set of design guidelines for sustainability.	The production of GreenWorks, the company’s first natural cleaner. Identification of a credible and durable definition of a natural cleaner.
Diffuse	Considered Design Team works with functions across the business to build literacy and establish goals and metrics for sustainable design. Members act as advocates and educators.	Identification of gaps in occupational sustainability literacy and needs for knowledge-sharing tools. Development of a tools such as colour coded material assessment scheme to reduce use of hazardous materials.	GreenWorks was developed with only a modest price increase altering the company’s view that a natural product would be niche. This message is now being shared throughout the business. The Eco Office is tasked with formal eco literacy.
First Step in Introducing Sustainable	Development of a small team called the Nike Environmental Action Team (NEAT).	Environmental department launched an interdepartmental pollution prevention	This pilot project was their first attempt at Sustainable Design

Design	NEAT's initial efforts focussed on recycling and education.	project to reduce formaldehyde emissions from wood finishing.	development.
Activities Prior to Sustainability Initiative	10 years' worth of activity and output from NEAT.	The development and output of a cross functional team called the Environmental Quality Advisory Team (EQAT).	One year spent convincing senior Strategy executives to give designers the freedom to explore the GreenWorks concept.

Table 4: Three Case Studies Characterising the A-B-C-D Process

Two aspects of these case studies are worthy of note within the context of this research. The first is that only the Clorox example describes a company in the nascent phase of eco-design. Nike and Herman Miller both had quite substantial experience of environmental development prior to the A-B-C-D activities. The Clorox example is also the only case study in which the authors explicitly described the key driver for eco-design activity (the identification of a market mega-trend), aligning with previous findings that initial activities are typically driven by a single issue. The second aspect is the relatively large resource commitment made by each organisation. In all three cases, cross-departmental teams were set up and sustainability knowledge from across the organisation was pooled to support efforts. In an environment where motivation and knowledge is low, the first eco-design project is likely to have to work to obtain this resource. As described in the Clorox example it took a year to convince the senior manager to provide the resource to focus on eco-design in any capacity.

Unlike the other methodologies reviewed here, the A-B-C-D approach provides a framework for best practice rather than a step-by-step process through eco-design implementation. Indeed reflecting the different approaches observed within each organisation the report finds that there is no specific starting point that offers the most potential, but that practitioners should instead locate the most tractable starting point. While this supports the idea that organisational characteristics have the greatest impact on eco-design implementation, the tool offers limited support for those setting out to develop their first project.

2.3.3 Eco-design Maturity Model (EcoM2) and Application Process

The EcoM2 and application process are described as *“a management framework, with a step-by-step approach, aiming to support companies in carrying out eco-design implementation”* (Pigosso et al., 2013).

The framework consists of two elements developed during Pigosso's research;

- 1) The EcoM2, which is an assessment model that “supports companies in the effective selection of eco-design practice to be integrated into the product development and related process, considering their strategic objectives and drives.”
- 2) The EcoM2 application process, which establishes a “continuous improvement framework for the incorporation of eco-design practices.”

Also based on the Deming's Plan-Do-Check-Act cycle, the application process is similar to those reviewed by Ammenberg and Sundin (2004), but with a greater emphasis on strategic definition and planning in the early stages, as shown in Figure 15.

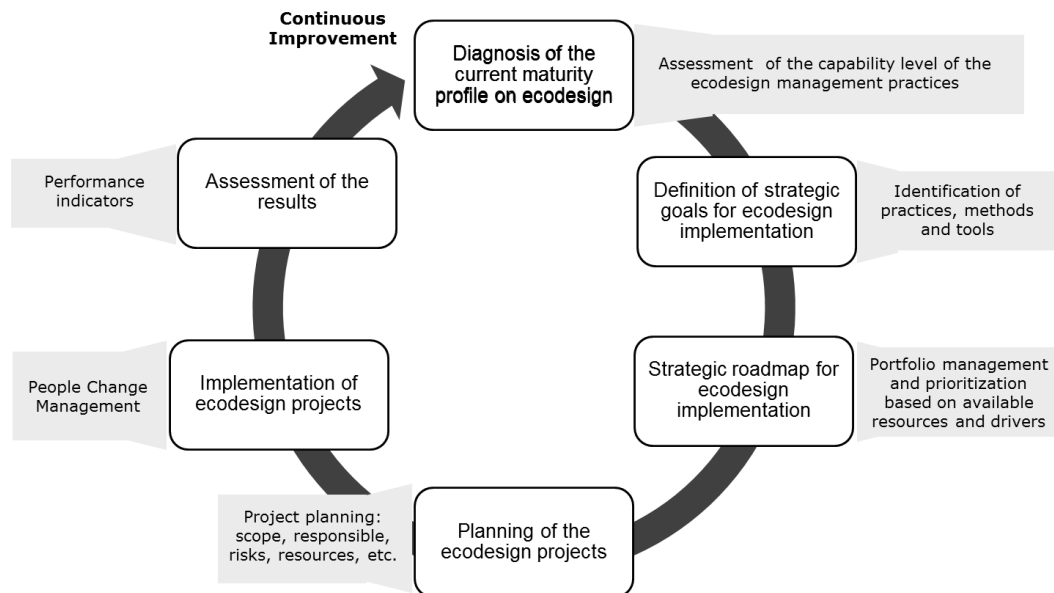


Figure 15: EcoM2 Application Process (Pigosso et al., 2013)

The activities described can be seen to be split into two groups based on who undertakes them; stages 1 and 2 appear to be externally supported by those with environmental knowledge and knowledge of the Eco-M2 methodology, although the specific role of this practitioner is not clear, stage 3-6 are explicitly identified as internal company activities. A brief description of each activity is given below.

Diagnose eco-design maturity - A company's eco-design maturity is determined through an assessment of their capability against 62 best practice eco-design management activities, such as the development of a company-wide environmental policy/strategy and the collation and dissemination of knowledge on eco-design

approaches and practices. To aid a systematic approach when eco-design knowledge is low, these management activities have been grouped into five levels of maturity that the company can work through chronologically (“a staged approach”). For companies with sufficient eco-design knowledge to do so, a continuous approach can be adopted allowing them to select management practices that align to the business goals and strategy. The data needed to assess maturity is collated through three activities; a product development process analysis, interviews with employees throughout the organisation and a consolidation of the findings of these activities.

Define strategic goals for eco-design – having identified the eco-design management practices that the company need to/want to implement, development projects are defined. During this stage applicable operational best practice and techniques and tools to support implementation are identified through an assessment of their relationships and dependencies. The project descriptions therefore detail the management practice being pursued, the associated operational practices that the company must implement and the tools available to support the achievement of this practice. The first two stages of this methodology are predicted to take 20 working days, resulting in the diagnosis of the company’s current eco-design maturity and the definition of improvement projects to increase maturity.

Define roadmap for implementation – the company then defines the strategic drivers for eco-design development and using this to decide which improvement projects to implement and when to implement them. The company can also restructure the projects to ensure compatibility with their working practices. The outcome of this stage is a timeline for the implementation of the improvement projects.

Planning eco-design implementation – the project plans are then defined in detail including the schedules, responsibilities, risks, resources, etc. This is again performed by the company who apply their usual project management practices to these new tasks.

Implementation of eco-design projects - the eco-design projects are then undertaken. Pigosso points out the importance of people change management during this stage, to help support the employees in working with new information and altering their working practices.

Result assessment – the final stage is to assess results of the improvement projects. In order to do this the company must have first identified performance indicators for each

project. The assessment of their performance against these indicators can then be used to perform the next eco-design maturity profile as part of a continuous improvement process.

Pigosso's work addresses many of the challenges of the nascent stage of eco-design implementation. Firstly, it addresses the ad hoc management characterised by early eco-design efforts by offering a predefined structure within which to work. Secondly, it broadens the view of eco-design outside the scope of product alteration. Finally, it addresses motivation by visually representing a company's current maturity level and offering a clear vision and roadmap for development.

The limitations of this methodology during the nascent stages of eco-design implementation come from its complexity, requiring application by someone with significant eco-design experience who also thoroughly understands the tool. In an environment where the motivations for eco-design are unclear to the company, this may be seen as a significant barrier to the use of this methodology. The tool also focusses on the implementation of management activities. While this is a recommended approach for successful eco-design implementation, the introductory phase is typically characterised by low management support and a technical, product-design-focussed understanding of eco-design. The application of a resource heavy tool that focuses on managerial activities is likely to be viewed as overzealous during the first project. Certainly, a large amount of knowledge relating to the scope and potential benefits of eco-design would be needed first. Similar to the POEMS approach, this tool also relies on the involvement of a company for whom a structured management process and continual process developments are commonplace. In the scenario where management structures are relatively fixed or largely unstructured, the application of this methodology is likely to contrast too greatly to the company's way of working.

2.3.4 Assessing the Application of these Tools during the Nascent Stage of Eco-design

The tools and methodologies described here offer a wealth of learning relating to the implementation of eco-design through a long-term continuous improvement process. The proven benefits of the systematic and strategic approach, promoted in each of these examples, provide clear goals for introductory activities.

The third objective of this research project is to develop a process that supports introductory eco-design activities. As such, Table 5, draws from the summaries provided above and assesses the application of each methodology against the

characteristic of companies in the nascent stage of eco-design, defined in Section 2.2.1.

Characteristic of the Nascent Stage	Applicability of the Tool Against this Characteristic		
	POEMS	A-B-C-D	Eco-M2
Low eco-design knowledge and no experience of eco-design achievements	Promotes a life cycle approach to identify key hotspots and organisational capabilities review. Aimed at building knowledge but offers limited support in obtaining it in the nascent stages.	Process is aimed at building knowledge. Promotes resource heavy methods of obtaining knowledge from the outset.	Provides a clear structure for the development of eco-design understanding. Is dependent upon the involvement of someone who understands the complex tool and its application
Low knowledge of eco-design tools and their application	As above.	The development of organisation specific tools is promoted, however no further guidance or support is offered.	Provides defined guidelines on the selection of eco-design tools. However the Eco-M2 tool is itself complex and resource intensive.
Eco-design viewed as a technical product development challenge.	Life cycle and management approach inherently broadens the scope of eco-design beyond product related activities. No activities aimed at justifying this broader perspective.	Promotes the development of cross-departmental team who focus on the full scope of eco-design. Provides no support for how to secure this resource.	Promotes a structure management approach to eco-design and assumes that the company understands the benefit of this.
Limited or ad hoc management and low resource commitment.	A management process who's success is dependent upon the involvement of those who can allocate and draw on available resource. No activities aimed	As above.	Promotes the development of management improvement processes. Assumes a willingness by the company to adapt their existing process in the

	at securing this support or commitment of resource.		pursuit of eco-design improvements.
Driven by legislative compliance or competitive survival.	Promotes the management of resources based on the existing drivers for eco-design including legislative or competitive issues.	Promotes the use of pilot projects aimed at addressing the primary driver for eco-design.	Capability improvement projects are aligned to the legislative and competitive environment.
Low understanding of the business opportunities or risks posed by eco-design.	Understanding the business risks and opportunities is not overtly dealt within the POEMS models.	Included within the activities of the eco-design focussed team. No support given for achieving this at the outset.	Addressed in later stages of process – following significant resource investment during early stages.
Low motivation towards environmentally improved products.	Market investigation and review of capabilities may improve motivation however methodology offers no direct support for increasing company motivation at the outset.	As a process that has derived from examples of eco-design success the framework does not overtly deal with early motivational issues.	Highly complex tool that requires significant commitment of time prior. Assumes motivation levels are sufficient to support initial resource investment. Once first stage is completed the visual representation of current capabilities vs best practice encourages motivation.

Table 5: Assessment of the Application of Existing Eco-design Implementation Methodologies during the Nascent Phase

Table 5 finds that the existing methodologies offer limited support to those seeking to take their first steps into eco-design development because they:

- Offer limited guidance for achieving key stages, despite the lack of available eco-design knowledge;
- Require the commitment of fairly significant resource, despite low experience or motivation of eco-design and limited management engagement;

- Require eco-design to be understood in strategic and operational terms, despite the technical product development view commonly observed.

2.4 Literature Review Summary and Research Direction

The literature review set out to examine the nascent phase of eco-design implementation. To do this, it first defined eco-design within the context of this research, as a process of organisational learning that sees the gradual integration of environmental aspects throughout the product development process, with the aim of achieving environmental improvements to the product throughout the product's life cycle. The introduction of eco-design was then examined and a characterisation of companies within the nascent phase of eco-design development was provided. Three eco-design implementation methodologies were then described and assessed against the nascent characteristics. The assessment found that these existing methodologies did not sufficiently address the specific challenges faced when conducting the first eco-design project. As a result, the need for a methodology or tool that meets the needs of a company in the nascent stage of eco-design development and supports the first eco-design project was identified.

3. Introductory Eco-design Case Study

The literature review identified the challenging organisational context within which eco-design must be introduced and identified a lack of support tailored to the needs of this nascent phase. In this section, the second stage of the observation phase is completed through a detailed description of an introductory eco-design case study. The depth of the description is included here to fully characterise the activities, opportunities, challenges and outcomes achieved during this project.

The key assumption driving this research project is that industrial eco-design outcomes can be improved by better planning of introductory eco-design activities. To examine this, the case study provides empirical evidence that allows examination of the interplay between the wider business context to which eco-design is introduced, the practical activity of introducing eco-design and the projects ability to support ongoing activity. The examination reveals the importance of planning introductory eco-design activities in accordance with the business context to ensure that adequate support and motivation for ongoing eco-design development.

The case study description summarises two years' work by the author during a KTP Project between the Company and the University of Bath. The overarching aim for this project was to initiate and embed eco-design knowledge and skills within the company, through the development of an environmentally improved product solution. The empirical evidence gathered during a two year eco-design case study forms the substantive part of the research, and enables research Objective 1 to be explored.

3.1 The Company

The organisation involved in this case study (hereafter referred to as the Company) were a design and manufacturing firm who produce touring caravans for the UK market. They were a family owned business that had grown throughout its history.

The company produced an average of 9,000 caravans annually and their profitability depended heavily on maintaining this output from their UK manufacturing site. The company typically offered four ranges, with around 5 different interior design layouts per range. To accommodate this variability whilst maintaining output, the manufacturing process was paramount and many of the company structures had evolved to ensure continuous and consistent manufacture. Indeed their engineers and designers had been trained to prioritise Design for Manufacture.

The company employed over 250 people, the majority of whom worked on the production line, while the management, design, and marketing, sales and commercial team's number around 40.

The Knowledge Transfer Partnership (KTP) project detailed in the following section began just after the release of the Company's new construction system. The new design resulted from a two year research and development project aimed at improving the weather proofing and durability of the caravans. To enable the new construction method the Company had also invested heavily in new manufacturing techniques and capabilities. The company were heavily promoting this new design when the KTP project began.

3.2 The KTP Project

The case study around which this research is centred was a Knowledge Transfer Partnership (KTP) set up between the University of Bath and the Company. The KTP Scheme is a government funded initiative that *"supports UK businesses wanting to improve their competitiveness, productivity and performance by accessing the knowledge and expertise available within UK Universities and Colleges."* (2011). The goal of this KTP was to take advanced eco-design and lifecycle assessment knowledge from within the University of Bath, and apply it to the design development of a touring caravan that offered commercial advantages over existing designs. To achieve this goal, a KTP associate (and author of this research) was hired to act as the knowledge transfer agent between the University and the Company. A diagrammatical representation of the structure and output of the KTP process is summarised in Figure 16.

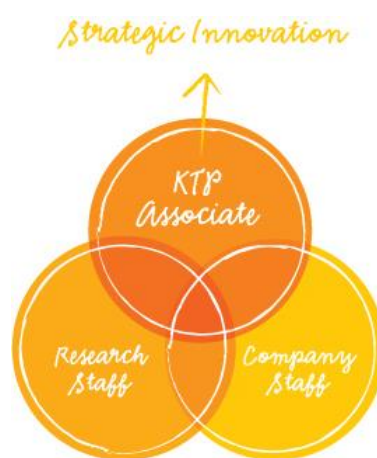


Figure 16: A Diagrammatical Representation Explaining The Structure and Intended Output of the Knowledge Transfer Partnership Scheme (2011)

The project was managed and performed by the author, removing it from the day-to-day activities of the existing design team and allowing research and development activities to take place without interrupting the critical and time pressured relationship between the design department and manufacturing line. Communication between the author and the management team was achieved through monthly meetings attended by the University lecturers, the Company's design manager and the Company's technical director and managing directors.

3.3 Background of the KTP Associate

At the time of employment, the KTP associate and author of this work, had studied and conducted eco-design product development within an educational context. Following University they had then been working for two years as an environmental building service engineer. This was the first eco-design project the Associate had undertaken and managed within a commercial setting.

3.4 The Project Aims, Objectives and Activities

To initiate the process, the University and Company had agreed on key aims and objectives for the project and produced a project plan detailing the main areas of work. The plan identified two Project Aims (PAs), three Project Objectives (POs) and ten Project Stages (PSs), summarised below.

Project Aims:

PA1 Design the new caravan family for 2012 onwards, that answered environmental issues whilst offering the lowest manufacturing costs to enable good profitability.

PA2 Transfer advanced eco-design and life cycle assessment (LCA) knowledge to the company's technical team.

Project Objectives:

PO1 Using life cycle assessment (LCA) techniques assess the environmental impacts of the current design.

PO2 From this assessment develop design and/or manufacturing alterations that address these impacts.

PO3 Conduct a thorough market analysis to assess the current market and identify a potential target market for environmental improvements.

Project Stages:

PS1 Literature Search

PS2 Streamlined LCA of Caravanning

PS3 Caravan Market Place Review

PS4 Sub-system Study (heating, 12V, gas, shower etc) Against Market Requirements

PS5 Environmental and Low Cost Material and Manufacturing Review

PS6 Towing Vehicle Perspective

PS7 Design Spec and Concepts

PS8 Detailed Design

PS9 Prototype Critical Elements

PS10 Eco-Product Prototype

Although the company had made changes to their internal operations on environmental grounds, including the introduction of a companywide recycling scheme and reduction of landfill waste by 50%, the KTP project was the company's first investigation into the environmental performance of their products.

3.5 The Project Plan

The project had a two year time frame and the PS's were planned to ensure the aims and objectives were met within this period. The Gantt chart included in the project plan has been reproduced in Figure 17, alongside the intended outcome of each.

Project Stage (PS)	Month								PS Intended Outcome
	3	6	9	12	15	18	21	24	
PS1 Literature Search									Establish state of the art in relevant science/technology
PS2 Streamlined LCA									Environmental aspects of caravanning and design options defined
PS3 Caravan Market Place Review									Design informed by market, target market defined
PS4 Sub-system Study Against Market Requirements									Caravan sub-systems understood against market and cost drivers
PS5 Environmental and Low Cost Material and Manufacturing Review									Materials and manufacturing techniques assessed against environmental aspects and selected for design
PS6 Towing Vehicle Perspective									Design informed by towing requirements and towing regulation

PS7 Design Spec and Concepts									Design requirements specification and development of 3 design concepts
PS8 Detailed Design									Design selection and detailing of elements to provide manufacturing cost savings
PS9 Prototype Critical Elements									Key design elements proved in prototype
PS10 Eco-Product Prototype									New caravan prototype and proving tests

Figure 17: Eco-design Case Study Project Plan Showing Project Stages, Timeline and Intended Outcomes

As can be seen this plan included typical product design and development tasks (Pugh 1991), such as market research, concept design and prototyping, with the addition of a streamlined Life Cycle Assessment (LCA) and environmental data gathering exercises.

3.6 The Lifecycle Inventory Study (LCI)

Due to the time and resource available to the lifecycle assessment, a streamlined LCI was conducted rather than a full LCA. A description of each of the LCI phases is given below.

3.6.1 The Goal

The goal of the environmental assessment was to identify the design key environmental hotspots. A product's environmental hotspots are defined as the features of a design that contribute most significantly to the lifecycle impacts (Dufrene et al., 2013). The results of the assessment were intended for internal use to help raise the environmental awareness of the company's technical team and direct subsequent design development.

3.6.2 The Scope

One mid-specification, mid-weight caravan was chosen as the reference system. The environmental assessment was to be completed by one person, working intensively for three months followed by iterative improvements as system understanding developed. The company had no access to LCA software, reducing availability to large materials and impact databases. To reflect the time, budget and resource constraints within the project, the following boundary conditions were agreed for the lifecycle assessment:

1) Life Cycle Inventory Study not Life Cycle Assessment

To remove potential subjectivity, simplify the process, improve communication with the company's technical team and reduce the need for impact assessment data, no impact assessment was conducted.

2) Defined Resource Flows

To reduce data requirements and enable a quick identification of the most significant impacts, resource flows were reduced to energy inputs and outputs (MJ) and their associated carbon dioxide equivalents (kgCO₂E). This simplification also supported communication with the company's technical team. N.B carbon dioxide equivalents are a measure of the global warming potential (GWP) of each of the 6 key greenhouse gases (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) normalised to that of CO₂. The normalisation allows the different impact potentials of each of these gases to be easily compared.

3) End-of-Life Phase not Included

During the iterative improvement work, it became clear that there was very little reliable data relating to the end-of-life treatment of caravans. Due to the relatively innocuous material make-up, the energy inputs and outputs related to the end-of-life were thought to be limited. As such the LCI study only included the material acquisition, production, transportation and use phases.

4) Inclusion of Primary Processes Only

To reduce data requirements and contain the study within reasonable limits, only primary materials, manufacturing and transport processes were included:

- Materials: where full material break downs could not be obtain, full component weight was assigned to the primary material, only the primary production processes were included.
- Manufacture: Energy consumption relating to onsite assembly, no supplier manufacturing process included.
- Transport: material and component delivery from tier one suppliers only, caravan delivery to retailer network not final customer.

Figure 18 summarises the scope of the LCI study conducted.

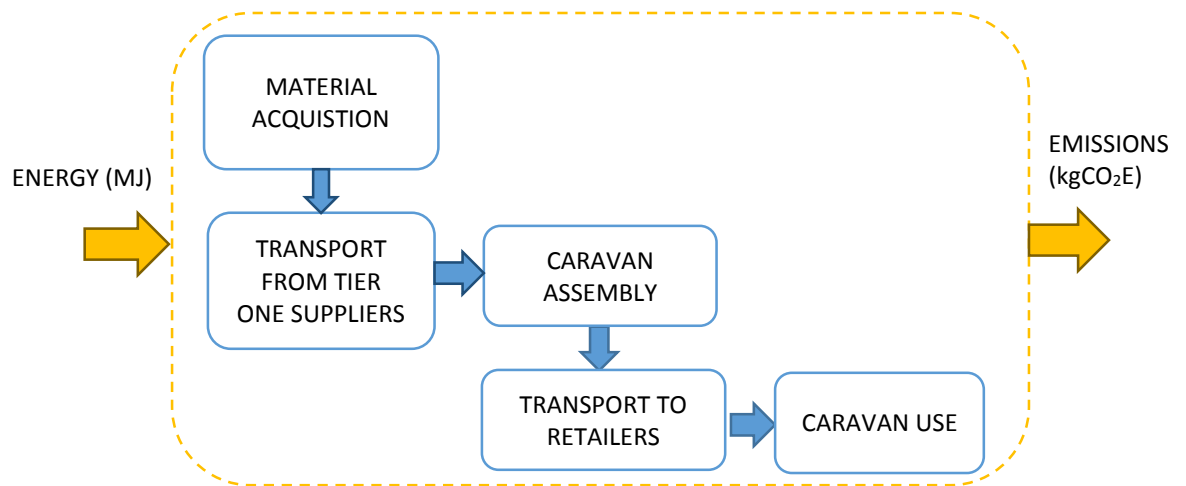


Figure 18: Product Life Cycle and Environmental Inputs and Outputs Included in the Streamlined LCI

Further boundary conditions were applied to each lifecycle phase to ensure sensible data collection. These conditions are included in each lifecycle phase descriptions below.

To ensure continuity when comparing the results of life cycle assessments the concept of the functional unit is important. The functional unit ensures that you are comparing two systems that provide an equivalent function to the user (Baumann and Tillman, 2004). It would be unreasonable, for example, to compare the environmental impact of a landline phone with that of a mobile phone, given that a mobile phone also provides the function of an address book, camera, map, satellite navigation device etc. As the goal of this study was to identify the products environmental hotspots, the definition of a functional unit was necessary to ensure future design comparability. As such the following functional description was defined as:

The materials, manufacture, use and transport of one caravan that enables four people to sleep, wash, eat, store luggage and relax and entertain themselves in comfort for 15 years' worth of holidays, in their chosen location.

3.6.3 The Life Cycle Inventory (LCI) Data Collection

The next stage was to gather the data needed to quantify the environmental inputs and outputs of each lifecycle phase shown in Figure 18. The following section details the data gathering exercises that took place to obtain this information. The description also highlights key challenges met during this data collection exercise.

The calculation of impacts from the LCI data was completed using two datasets. Their details and application are listed below:

Database 1: Inventory of Carbon and Energy (ICE) database (Hammond and Jones, 2008), a publically available database developed by the University of Bath. The ICE database collates embodied energy and emissions figures from publically available peer reviewed sources.

Database 2: Ecoinvent 2.2 database accessed through the University of Bath (Ecoinvent Association, 2012).

Material Acquisition

The total energy consumption of the material acquisition phase is a summation of the energy required to manufacture a material into a usable form, ready for delivery at the supplier's gate. The energy consumption involved in this transformation is known as a material's embodied energy from cradle-to-gate (Hammond and Jones, 2008)). To calculate the embodied energy and the associated emissions, the following data was required:

- The material make up of each component.
- The weight of each component.
- The primary manufacturing process required to produce each material.
- The energy related to the extraction and processing of each material, known as the embodied energy.
- The emissions produce during the extraction and processing of each material.

The bill of materials for the selected caravan contained over 7,500 components, purchased from 97 different suppliers. These components range from sheet metals, which undergo secondary processing on site, to complete appliances, such as a cooker, which are installed into the caravan. To obtain this data, every supplier was contacted with a request for the material make up, weight and primary manufacturing processes used to make the parts they supplied. The sum of each processed material was then calculated. Database 1 was then used to assign total embodied energy and GWP values to each material, allowing the total caravan value to be summed.

Collating the material information took 6 months to complete, making it be far the most resource intensive. There were a number of contributory factors; firstly, the number of components for which data was needed and the number of suppliers with which contact had to be made; secondly, the complexity of supply chains; and finally, the novelty of the information request. The final point is of particular interest, as it is specific to the first environmental study completed by a company and despite the

significant challenge it poses, it is not typically discussed in depth in reviewed case studies. The information request is novel because the caravan supply chain is used to communicating in terms of functionality, weight and cost, and as a result they intuitively understand these aspects of their products. In contrast materials are less often discussed, trade names are often used and due to the complex nature of supply chains constituent materials are not always known. In the simplest cases this increased the time taken for supplier to provide a material breakdown, in others it prevented the data being available at all. In some instances the request was met with suspicion as to why such detailed information was needed and the intended or potential use of it. Additional time was needed to educate and reassure these suppliers, however in some instances they were still only happy to provide high level information. In total 92% of the caravan's weight was accounted for through supplier provided information, internal component analysis and high level material assumptions.

Material Acquisition Results

The embodied energy and global warming potential were calculated for the 100% virgin materials, industry average virgin/recycled mix material and the highest recycled content. In many cases, due to the recyclability of the material or low market value for recycled material these figures are the same in all instances. Table 6 shows the variation between these three models.

	Total Embodied Energy (MJ)	Total GWP (kgCO₂e)
100% virgin material	110,247	5,326
Industry average material	96,259	4,760
Max. recycled content	72,199	3,633

Table 6: Total Embodied Energy and Carbon Dioxide Equivalents for 100% Virgin Material, Industry Average Material and Maximum Recycled Content

The industry average values were used in the overall LCA to reflect the most realistic scenario; the comparative figures were communicated to the company management to help understand the relative impact made by specifying recycled content. The embodied energy of the material and global warming potential was calculated for the industry average recycled content, as shown in Figure 19. 'Other' materials were those with a less than 1% contribution to the overall weight. 'Unknown' materials were those that could not be definitively identified by the suppliers or the team.

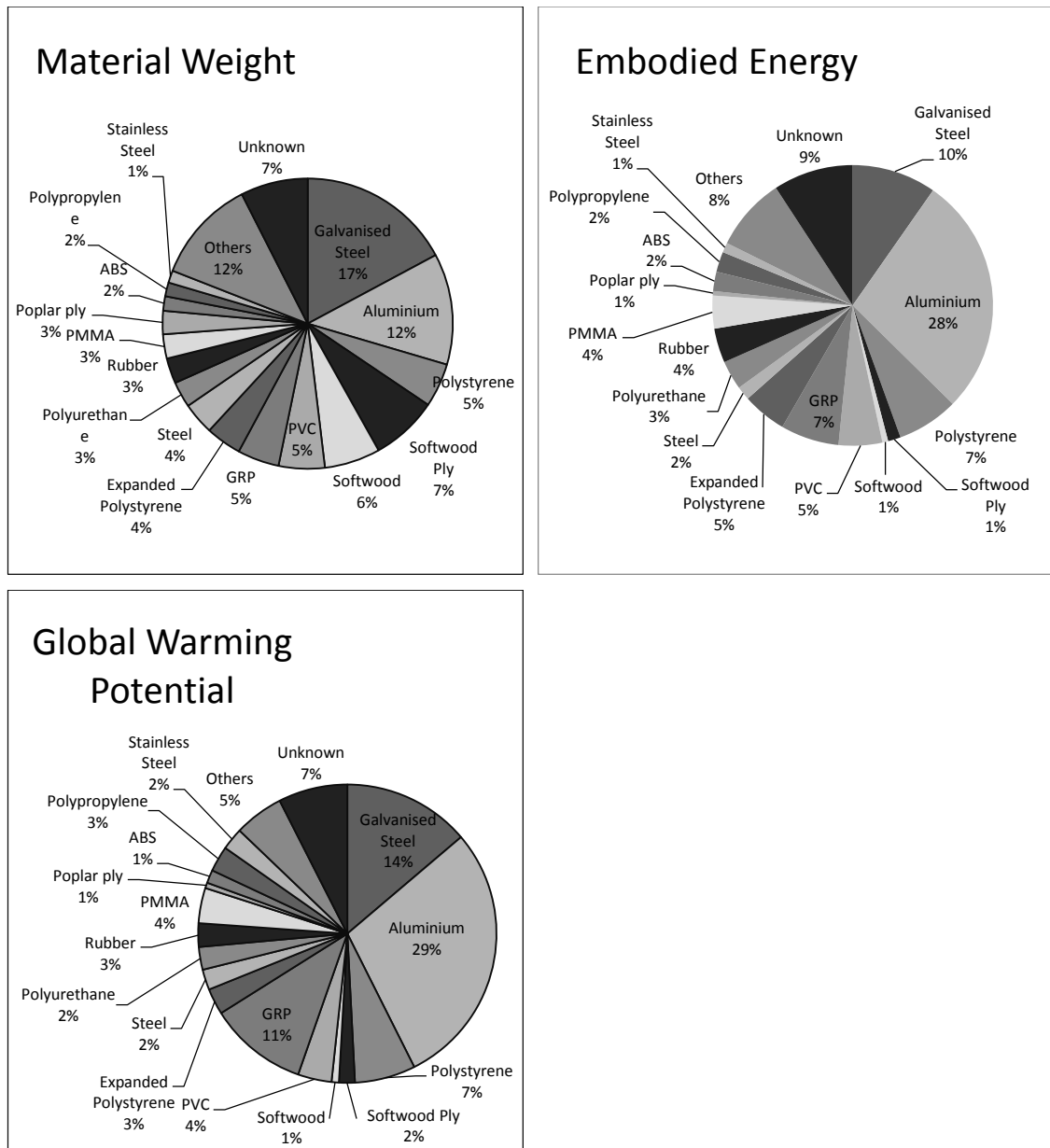


Figure 19: The Relative Material Make-up, Embodied Energy and GWP Values for the Material Acquisition Phase of the Mid-spec, Mid-range Caravan using Industry Average Recycling Rates

Representing the data in this way enables easy identification of the materials with a high impact to weight ratio. Table 7 lists the four materials with the highest embodied energy ratio.

Material	Embodied Energy (MJ/kg)	GWP (kgCO ₂ E/kg)
Aluminium	155	8.24
GRP	100	8.1
Polystyrene	100.09	2.7

Stainless Steel	56.7	6.15
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Table 7: Highest Impact Materials Used within the Caravan Design, Shown on a Scale of Impact to Weight Ratio

Transportation: Inbound and Outbound Logistics

The transportation phase of this study included two delivery processes; the incoming delivery of materials and components from first tier suppliers, and the outgoing delivery of the final product to dealership's across the country. The transportation phase does not include towing by the customer, which is included in the use phase figures.

To calculate total energy and emission for this lifecycle phase, the following data is needed:

- Transportation distance from tier one suppliers to manufacturing site.
- Transportation methods from tier one suppliers to manufacturing site.
- Transportation distance from manufacturing site to retailers.
- Transportation methods from manufacturing site to retailers.
- Mass associated energy and GWP for each figures transportation method (MJ/kg, kgCO₂E).

Alongside the information regarding materials and component mass, suppliers were asked to provide the transportation methods used to deliver their components to the caravan manufacturing site. Transport distances for each component were then calculated using online mapping tools.

A list of all the locations within the dealer network was then obtained from the logistics team and the distances were again calculated using online mapping tools. As the LCI Study was being completed on one caravan, an average of these distances was taken as a representative delivery distance.

Database 2 was then used to assign mass associated energy consumption and GWP values for each mode of transport was assigned to the mass of each component, allowing the total transport impact figures to be summed.

The majority of the data collated to model this phase comes from internal logistics knowledge held within the company or supply chain companies. As such data collection is generally less cumbersome than the materials data. The reduction in the burden of data collection was also achieved by the exclusion of tier two suppliers. Many components are likely to go through multiple suppliers before reaching the

company's tier 1 suppliers and this study chose to omit these stages. While this introduces variability into the modelling, as tier one suppliers range from manufactures to local dealerships, the difficulty of obtaining more detailed logistical information about every part and the assumption that the contribution of this life cycle phase would be small, justified the decision. To validate this assumption that this phase would be relatively small, a typical journey from China to the company site was calculated and applied to the full weight of the caravan. This raised the relative energy consumption and emissions to 17% and 15% respectively. As this was known to be far greater than the real value and it still represented a minor contribution, this exercise was seen to validate the assumption.

Transportation: Inbound and Outbound Logistics Results

The approximate 7,500 components in a Pegasus 534 were calculated to travel a total of 28,509 miles from their tier 1 suppliers to the company assembly line. This delivery was made up of a combination of vans, HGV's, trains and ships. To calculate the impact of these journeys the weight of each component was multiplied by the distance it travelled. Energy and emissions factors were then taken from Database 2. Table 8 summarises the energy and emissions used and the total energy and emissions figures calculated.

Inbound Logistics (Component Delivery): Primary Data			
Transportation Mode	Energy Consumption /tkm (MJ/tkm)	GWP/tkm (kgCO₂e/tkm)	Total Transport Type Delivery (tkm)
Van	34.03	1.941	1
HGV (<7.5 tonnes)	10.36	0.626	8
HGV (7.5-16 tonnes)	4.336	0.265	30
HGV (16-32 tonnes)	2.583	0.152	370
Train	0.765	0.05	25
Ship	0.17	0.011	418
Total Energy Consumption and GWP	1334 MJ	79 kgCO ₂ E	

Table 8: Data Used to Calculate the Energy Consumption and Emissions for Delivery of Components from Tier 1 suppliers to the Company Assembly Line

Within this study the delivery of the caravan to a dealer for sale to the customer is also included within the transportation phase. The company's dealer network is spread across the country so it was agreed that a mean distance would be calculated and used within caravan life cycle.

The data used to calculate the delivery of one caravan from the company to a retailer at mean distance is shown in Table 9. Also shown in Table 9 is the total transport figures calculated by summing the inbound and outbound logistics.

Outbound Logistics (Caravan Delivery): Primary Data	
Weight of Caravan (kg)	1378
Distribution Transportation	3.5 – 7.5 tonne diesel
Embodied Energy / tkm (MJ/tkm)	10.36
kgCO ₂ E / tkm (kgCO ₂ E/tkm)	0.626
Mean Distance to Retailer (km)	282
Total Energy Consumption for Delivery (MJ)	4037
Total Emissions for Delivery (kgCO ₂ E)	244
Total Transportation Energy Consumption (MJ)	5371
Total Transportation CO ₂ Equivalents (kgCO ₂ E)	323

Table 9: Data Used to Calculate the Energy Consumption and CO₂ Equivalent Emissions Related to the Delivery of One Caravan to a Retailer

Caravan Assembly

To obtain a holistic view of the energy consumption and GWP figures related to the manufacturing of the caravans, the energy consumption for the whole site was included. As such these figures include the energy consumption related to marketing, sales, procurement and aftersales activities.

To calculate the total energy consumption and GWP for this phase the following data was required:

- The total energy consumption of the manufacturing site and the source of that energy.
- The total number of caravans produced annually.

- The GWP of each energy source.

To obtain this data all gas, electricity and oil bills for the previous year's production were obtained from the finance department. To get an average figure per caravan the total was divided by the previous year's production total.

The GWP of gas and oil and electricity produced in the UK was again taken from Database 2, allowing the total energy consumption and emissions figures for the manufacturing phase to be calculated.

Caravan Assembly Results

A breakdown of the three energy sources used at the Company's manufacturing site is shown in Figure 20, alongside the GWP figures related to this energy consumption.

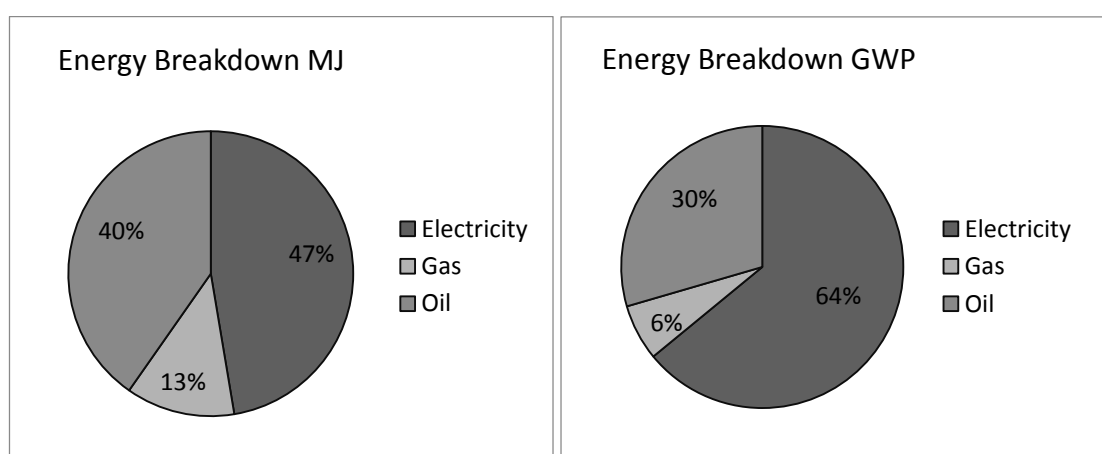


Figure 20: Breakdown of energy use within the factory. GWP Emissions related to Factory Energy Use

Table 10 shows the figures used to calculate the total energy and GWP for the manufacturing stage.

Total Energy Consumption and Emissions for On-site Manufacturing Activities	
On-site electricity consumption	950,531 kWh (3,421,912MJ)
On-site gas consumption	248,197 kWh (893,508MJ)
On-site oil consumption	808,442 kWh (77,950 litres)
GWP of UK Electricity	0.527 kgCO ² E /kWh
GWP of UK Gas	0.203 kgCO ² E/kWh
GWP of Light Oil	2.96 kgCO ² E /litre

Total Energy Consumption for On-site Manufacturing	7,225,811 MJ
Total Emissions from On-Site Manufacturing	782,046 kgCO ₂ E
Number of Caravans Built in 2009	7120
Total Energy Consumed for the Manufacture of One Caravan	0.143MJ
Total GWP for the Manufacture of One Caravan	0.015 kgCO₂E

Table 10: Data Used to Calculate the Energy Consumption and GWP Related to the Manufacture of One Caravan

Caravan Use and Project Stages 3 and 4

The caravan use phase modelled in this study includes all the energy consuming processes related to the customer's use of the caravan. These processes can be separated into two primary activities; towing the caravan and using the caravan when stationary. To calculate the energy consumption and emissions related to the in-use phase the following data about the customer and the tow vehicle was needed:

- The annual caravan towing distance
- The fuel consumption when towing the caravan
- The type of fuel used by the tow vehicle
- The on-site energy consumption figures and the constituent energy sources used to generate it.
- The GWP of each energy source used.

Modelling the in-use phase is complex because each of these contributors will vary greatly between users. As the LCA was being used to identify the relative significance of each life cycle phase, it was important that this variability was understood and incorporated within the model to prevent disproportionate weighting. To achieve this three use scenarios were modelled; low, medium and high use. To accurately understand what constituted low, medium and high use, a significant customer data set was needed. As a small business, the company's customer knowledge was largely qualitative and tacit in nature. To address the lack of quantitative data the team decided to conduct a customer survey. Working closely with the marketing department a survey was developed to address the data needs of the LCA whilst incorporating questions that informed the wider business, see Appendix 1. This was sent out to the company's mailing list and a total of 2,689 responses were collected.

The questionnaire was used to model low, medium and high towing distances, fuel consumption figures, holiday lengths and group sizes when on holiday, all of which helped inform the use phase calculations. The common use of diesel powered 4x4 tow vehicles was also identified.

The only information not obtained via the customer questionnaire was the power consumption when on site. Due to the difficulty of measuring energy consumption when in a caravan, power consumption was omitted from the questionnaire. To tackle this data gap inline energy monitors were given out to company staff for use on a catered sites throughout the year. These were connected between the mains plug and the caravan to ensure all energy use was documented. To accompany these monitors, staff were asked to complete a questionnaire documenting the length of their holiday and the number of people in their caravan, allowing the calculation of an average daily use per person.

There are a few limitations to this data collection method. The first is that the energy usage only documents those on catered sites where energy is typically free, omitting those who stay offsite. The second is that the gas and battery usage are not included. While mains electricity consumption can be seen as an alternative to battery usage, accurate gas usage could not be measured. Instead staff were asked to document their gas appliance use. This revealed that gas was typically only used for cooking and BBQ's when an electricity supply was available and this was estimated at 20% of the electrical consumption.

Full figures for this life cycle phase were then calculated by summing the low, medium and high towing figures with the equivalent low, medium and high on-site energy figures. Database 2 was used to assign emissions ratings to each constituent energy contribution.

Collating the data for this phase took place over a five month period and was not completed until the end of the first year. Evidently a large amount of additional work was required due to the lack of quantitative in-use data available in the business. The data obtained by the customer survey and in-use studies was extremely useful to the business, however the extent of the resource required was not well captured in the initial project plan, despite the novelty of the information needed.

Although not evident in this initial description, the most significant challenge posed by the use phase related to the data collection methodology. To calculate the energy

consumption of this use phase average fuel consumption figures were taken from customer data. While this methodology allowed the in-use environmental impacts to be calculated in this first LCI, it does not lend itself to the modelling of small design changes. If for example, the caravan mass is reduced by 10kgs, the company would need to prototype this caravan and physically compare the fuel consumption impact as a result. To achieve this a much more detailed understanding of the relationship between mass and fuel consumption was needed, however due to the focus on product development in this project, this was seen as outside the scope of the project.

Caravan Use Results

The data used to calculate low, medium and high use scenarios are shown in Table 11.

Towing Figures for Use Scenario's			
	Low	Medium	High
Reduction in Diesel Consumption (MPG)	9	13.05	21
Annual Towing Distance (miles)	500	2000	4500
Daily Electricity Use per Person when on-site (MJ)	4.14	8.8	15.74
Daily Gas Consumption per Person (MJ) (estimated 20% of electricity figure)	0.83	1.76	3.15
Annual Number of Days on Holiday	10	50	204
Number of People on Holiday	2	4	7
Embodied Energy for UK Diesel (MJ/litre)	38.6		
Emissions for UK Diesel (kgCO ₂ E/litre)	2.66		
In-use Life Time of a Caravan	15 years		
Energy Consumption over 15 yr lifecycle (MJ)	43,003	233,947	1,022,132
GWP over 15 yr lifecycle (kgCO₂E)	3,062	18,217	97,170

Table 11: Data Used to Calculate the Low, Medium and High Energy Consumption and GWP Figures for the In-use Phase

Figure 21 represents this data as relative percentages of the total, helping to visualise the contribution made by each in-use activity.

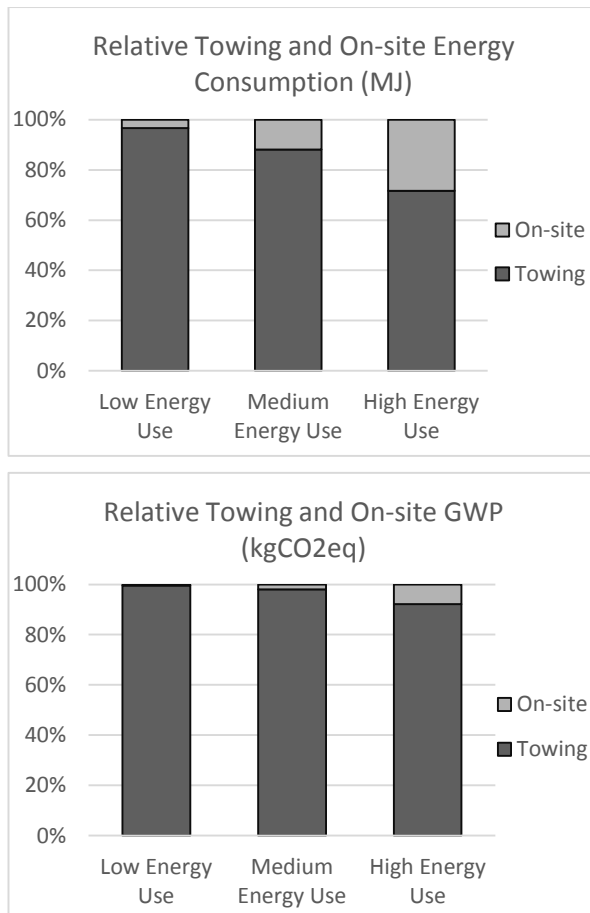


Figure 21: The Relative Contributions to Total Energy Consumption and Emissions made by Towing and Use On-site

As shown by the charts above the fuel consumed when towing the caravan makes the most significant contribution to both the energy consumed and emissions generated by the in-use phase.

3.6.4 Total Lifecycle Results

Table 12 collates the results of each of these lifecycle stages and calculates the total energy consumption and CO₂ equivalents figures for the lifecycle of one reference caravan.

Life Cycle Stage	EE (MJ)	GWP (kgCO ₂ E)
Materials	96,259	4,760
Transportation	5,371	323
Manufacture	0.143	0.015
Average In-Use	233,947	18,217
Total	335,467	24,379

Table 12: The Total Energy Consumption and GWP for Each Life Cycle Stage of One Reference Caravan

Presenting this data in bar chart form, as shown in Figure 22 shows the relative impacts of each lifecycle stage.

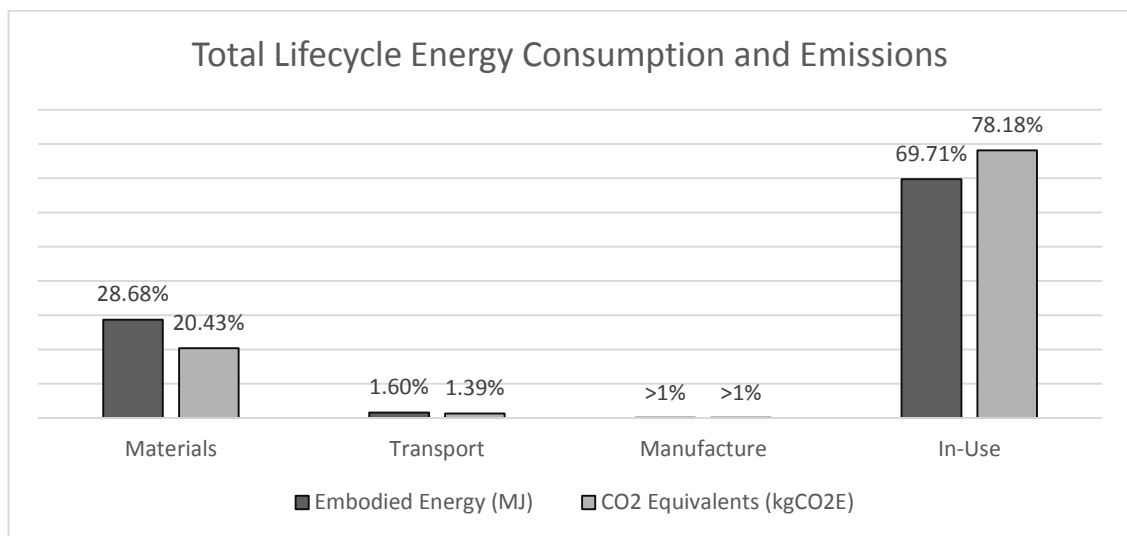


Figure 22: Embodied Energy and Emissions for Each Lifecycle Stage of the Caravan's Streamlined Life Cycle Assessment

As shown in Figure 22, the materials and in-use phases represent the highest contributions to both the energy consumption and GWP figures, the relative magnitude of the transport and manufacturing contribution was deemed small enough to be insignificant.

3.6.5 The Environmental Hotspots Identified by the Simplified LCA

The LCA results clearly indicate that the in-use and materials phases have the most significant impact over the life cycle of a caravan. As shown in the in-use results, this phase is dominated by the fuel consumption during towing. The power required to move the caravan is related to three design features; the aerodynamic drag, the weight and the rolling resistance of the tyres. The material phase results show that the most

significant contribution came from the use of aluminium within the design. From these environmental hotspots, four design development areas were agreed:

1. Reduce the caravan's aerodynamic drag
2. Reduce the weight of the caravan
3. Reduce the rolling resistance of the tyres
4. Reduce the use of high embodied energy materials (particularly aluminium)

3.6.6 The Outcomes and Challenges Presented by the LCA Process

Conducting the first LCA within this company provided the company with a body of data that improved their understanding both of the product and the market; however there were also significant challenges. Table 13 summarises the benefits and challenges.

The Beneficial Outcomes of the LCA Process
<ul style="list-style-type: none"> - Identification of the key environmental hotspots of the company's existing design and lifecycle phase weighting - Improved knowledge of the material makeup of their products - Communicated company's interest in environmental impacts to the supply chain - A quantitative understanding of the customers and their use of the caravans
The Challenges Faced During the LCA Process
<ul style="list-style-type: none"> - No access to LCA software, increasing resource requirements, limiting access to current data and the range of assessment categories. As process was not embedded within the company there was also no justification for investing in software. - Novelty of the data requests needed to complete LCA. Most significantly felt when requesting materials data from suppliers and when modelling the in-use phase. - Complexity of data needed to establish an LCA model that was easily repeatable and able to assess the impact of future design changes.

Table 13: The Beneficial Outcomes and Key Challenges presented by the LCA Process within this Context

3.7 Design Development to Address Environmental Hotspots

The environmental hotspots identified by the life cycle assessment were presented to the project team, providing clear areas of focus for Project Stages 7 and 8; Design Specification, Concept Development and Detailed Design. To address these design hotspots it was decided to split the work into four dedicated development projects. The following describes the activities undertaken and outcomes of each development project.

3.7.1 Design Development Project 1: Reducing Aerodynamic Drag

The company had not previously addressed the aerodynamic performance of their caravans, so the first step was to better understand the physics.

Understanding Aerodynamic Drag

The term aerodynamics is used to describe a number of 3-dimensional forces which occur when a body moves through a fluid (Hucho and Sovran, 1993). In this case, the study investigates the aerodynamic effects that act on a caravan as it moves through air. The study begins with a brief summary of the aerodynamic forces that act on a caravan as it moves through the air and the design features that impact upon the magnitude of these forces. The second section describes the testing and concept development that took place to reduce aerodynamic drag. It should be noted that where possible a tow car has been included within the studies to ensure a realistic representation of caravan use.

Aerodynamic Forces when Towing a Caravan

When a caravan is towed along a road it experiences a series of aerodynamic phenomena, which resist its movement and increase the fuel consumption of the tow vehicle. These can be roughly broken down into three groups; drag, which acts parallel and opposite to the direction of motion; lift, which acts perpendicular to the direction of movement, and the pitch moment, which pivots the caravan at the axle (Darling and Staden, 2003). For a road vehicle, by far the most prominent of these aerodynamic forces is pressure drag (Hucho and Sovran, 1993). For simplicity the other aerodynamic forces associated with viscous friction have been omitted from this study.

Pressure Drag

The pressure drag force, or aerodynamic drag, acts opposite to the direction of movement and therefore increases the engine power and fuel required to move it forward. The aerodynamic drag force (F_d) can be calculated using the following equation:

$$F_d = \frac{1}{2} \rho v^2 C_d A$$

The power required to overcome this drag force is given by the equation:

$$P = F_d v$$

As the density of the air (ρ) and the velocity of the air and caravan (v) are uncontrollable factors and the cross sectional area of a caravan (A) is fixed by the user requirement to stand, the main area of design potential is the drag coefficient (C_d), which is predominantly linked to the shape of the object.

The drag force experienced by a caravan results from the difference in pressure between the front and rear faces (Barnard, 2001). As a caravan moves through the air, the streamlined air flow puts greater pressure on the leading face than the turbulent air generated at the rear. High velocity, low pressure, turbulent regions are generated when air separates from the moving body. Separation occurs when the body profile changes suddenly. Minimising sudden or sharp protrusions or curving the rear face at the point of separation, will therefore lower aerodynamic drag by preventing separation of the fluid flow from the body profile, and in turn reducing the delta between the front and rear faces. As the greatest region of turbulent, low pressure, air is generated at the rear of an object, known as the wake, design changes at the rear of the body are found to have the greatest impact. Figure 23 shows how the removal of sharp protrusions and the introduction of a gradual curve at the rear can minimise air separation and reduce the development of turbulent air around the body (Freeman).

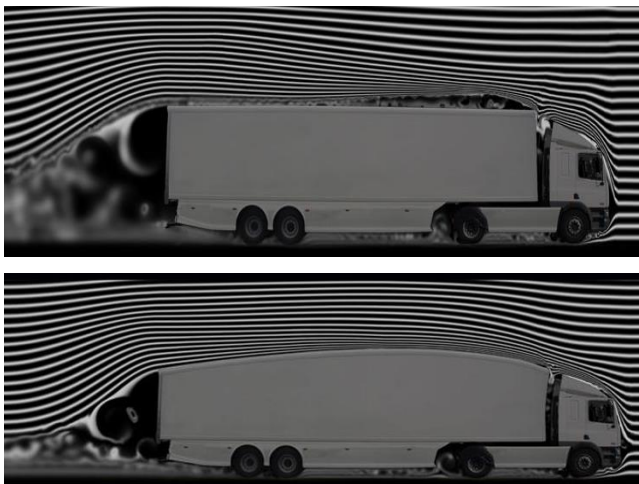






Figure 23: Air Flow Visualisation Wind Tunnel Analysis of an HGV with Reduce Cross Sectional Rear Area and Consequential Wake Reduction (Freeman).

Design Features that Contribute to Pressure Drag

The design features contributing to the caravan's pressure drag were inferred from the need to reduce protrusions and minimise the cross sectional area at the rear of the vehicle. Potential design improvements were then developed. Both are summarised in Table 14. The design improvements are listed in ascending order according to the scale of design change they represent.

Design Features Identified as Contributors to the Caravans Pressure Drag	Potential Design Improvements
<p>Square rear corners and bumpers, constant cross section.</p> 	<ul style="list-style-type: none"> - Redesign the rear lights and bumper, bringing lights into the caravan to help bring the external profile in line with the body of the caravan. - Introduce a curved rear end to reduce cross sectional area and protrusions. - Redesign the rear shape of the caravan completely.
<p>Exposed wheels and protruding wheel arches.</p> 	<ul style="list-style-type: none"> - Install deflectors in front of the wheels to channel air around them. - Bring the wheels in slightly and develop flush wheel arches. - Design a wheel arch that more closely matches the wheel shape. - Introduce wheel covers that allow brake cooling but improve air flow. - Develop new wheels with fairings and low tread depth.
<p>Sharp corners on leading face, protruding bumper profile</p> 	<ul style="list-style-type: none"> - Reduce the protruding profile of the bumpers. - Increase the curvature at the front of the caravan to remove outer corners.
<p>Exposed structure beneath main body of the caravan</p> 	<ul style="list-style-type: none"> - 'Clean up' the layout and design of the services attached to the underbody to reduce drag. - Cover underbody with a formed sheet to create a smooth profile. - Combine the chassis and floor into one design to minimise protrusions.
<p>Protruding roof lights, ventilation and TV aerial</p>	<ul style="list-style-type: none"> - Reverse direction of roof light to create tapered trailing edge. - Install deflectors at the leading edge of all protrusions. - Source flush aerial or work with




	<p>suppliers to reduce design drag.</p> <ul style="list-style-type: none"> - Redesign roof lights or their interface with the caravan to make them flush.
<p>Protruding elements on both sides of the caravan</p> 	<ul style="list-style-type: none"> - Introduce deflector at the leading edge. - Redesign the installation of these parts to make them flush with the walls. - Work with the suppliers to redesign the door.
<p>Gap between car and caravan creates an area of very low moving, low pressure air at the rear of the car increasing drag on the tow car.</p> 	<ul style="list-style-type: none"> - Design tent style bolt on that can be put up when travelling. - Redevelop the shape at the front of the caravan to help reduce this gap.

Table 14: The Caravan Design Features that Contribute to Pressure Drag and the Potential Design Options Identified to Reduce It

Investigating Pressure Drag and Proving Design Potential

The design options were shared and discussed with the KTP team. During these discussions it became apparent that, due to the novelty of aerodynamic design, more data was needed to assess and evaluate the impact these design changes. To achieve this three projects were set up to investigate the relationship between the caravan's profile and the aerodynamic drag it experiences. The first aimed to test the impact of a 747mm curve at the rear edge, a current design concept that the company were developing. The second was to use the work of a Masters project at the University of Bath (Berry, 2010) to better understand the air flow around different caravans using computational fluid dynamics software (CFD). The third project was to build full size prototypes to investigate the air movement around specific design options selected from Table 14.

Determining the Impact of a Curved Rear Edge on Tow Car Fuel Consumption

When the KTP project began the company were in the process of developing a small, low specification range with a 747mm curve at the upper rear edge. The design concept had been developed for aesthetic reasons, however the removal of a sharp protrusion and the consequential reduction of the cross sectional area at the rear, provided the opportunity to investigate the aerodynamic impacts of this design change.

Although the design change being tested related to the aerodynamic drag of the caravan, the tow car's fuel consumption was of most interest to the company as it provided a figure that could be used to market the product. As such a test was developed to understand aerodynamic drag improvements through the fuel savings they provided. The full details of this testing were detailed in the report written at the time of testing which can be seen in Appendix 2.

The results of this testing found that the curved rear did achieve a fuel saving which equated to an average of 5%. Taking the average annual towing distance of 2000 miles, this provided a cost saving of between £21 and £25 per year, dependent upon diesel costs. These low cost savings were not deemed high enough to be used in promotional material, however the marketing department did use the 5% fuel reduction figure.

Using Computational Fluid Dynamics (CFD) Software to Confirm and Understand the Aerodynamic Effect of a Curved Rear Edge

Matt Berry's Masters project (2010) aimed to "assess the effect of the caravan body shape on any reduction in drag, corresponding to a reduction in fuel consumption" (Berry, 2010). Using a previous wind tunnel study (Standen, 1999) to validate the results, the project conducted CFD analysis on various caravan shapes. The research project involved three studies, which were used to improve the KTP teams understanding and as such are detailed here.

1. Aerodynamic Study One was conducted to validate the results of the CFD against the 3D wind tunnel testing completed by (Standen, 1999). The CFD plots for the three most relevant shapes are shown in Figure 24.
2. Aerodynamic Study Two compared the air flow over a square backed caravan, a slopped back caravan and a rear curve, shown in Figure 25.
3. Aerodynamic Study Three (Figure 26 and Figure 27) used the results of test 2 to develop a design that would further improve aerodynamic drag.

All tests were completed in 2D rather than 3D due to complications experienced when modelling 3-dimensional effects within the time frame of the project. As stated in the report *“this meant that no 3-dimensional effects such as induce drag could be simulated and therefore any 2D results must be treated with caution. However, it was felt that the 2D results would give a clear indication of any relative benefits of changing the caravan body shape.”*

Aerodynamic Study One – Validating CFD results against Standen’s Physical Wind Tunnel Testing

To validate the CFD results, Aerodynamic Study One ran simulations of the three most common caravan shapes studied by Standen and compared the results. The comparison found that the absolute drag coefficient values did not match those calculated by Standen, ruling out the use of the 2D methodology to calculate a drag coefficient number. However when comparing the percentage improvement of each design change the 2D results were found to achieve the same deltas as the wind tunnel test. This validated the use of the 2D methodology as a tool to identify percentage improvements against a baseline. The air velocity profiles produced in each 2D study can be seen in Figure 24, with the darkest areas representing low pressure air flow.

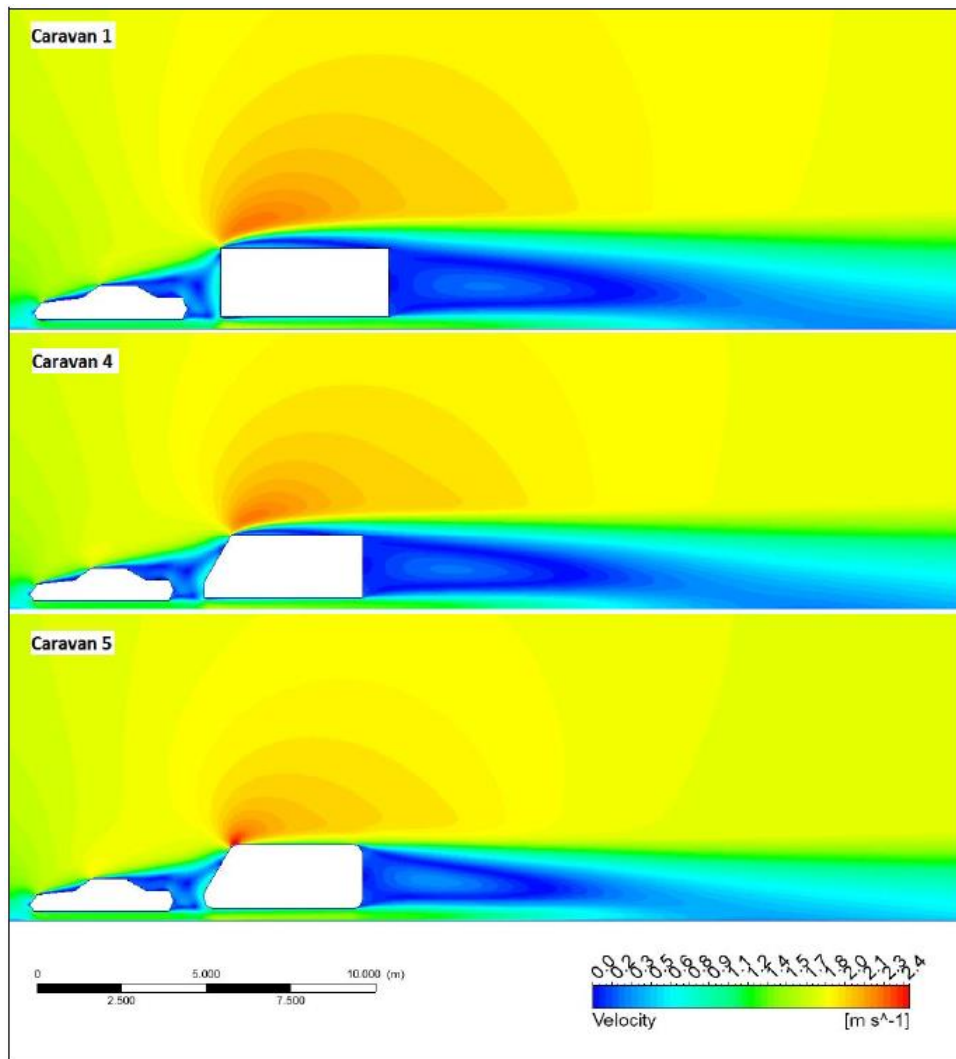


Figure 24: Study One: Comparison of Velocity Profiles for 2D Air Flow when introducing a slope front face and curved edges front and back. Image taken from the work of Berry (2010)

The air velocity profiles identify significant reductions in the wake whenever curved edges are introduced, but most notably at the top front and rear edges of the caravan. The study also identifies the positive impact made by sloping the leading edge of the caravan.

Aerodynamic Study Two – Comparing Current Caravan Design with the New Curved Rear Edge Design

In the second study Berry proposed two ways of reducing the wake area behind a typical caravan; introducing a continuous slope to the top face and curving the rear edge. The CFD plots, shown in Figure 25, found that the introduction of a curve at the rear edge produced the most significant wake reduction. Unlike Standen's study, Berry modelled the caravan with an SUV tow car, the most common tow car as identified by the LCI's in-use phase customer survey.

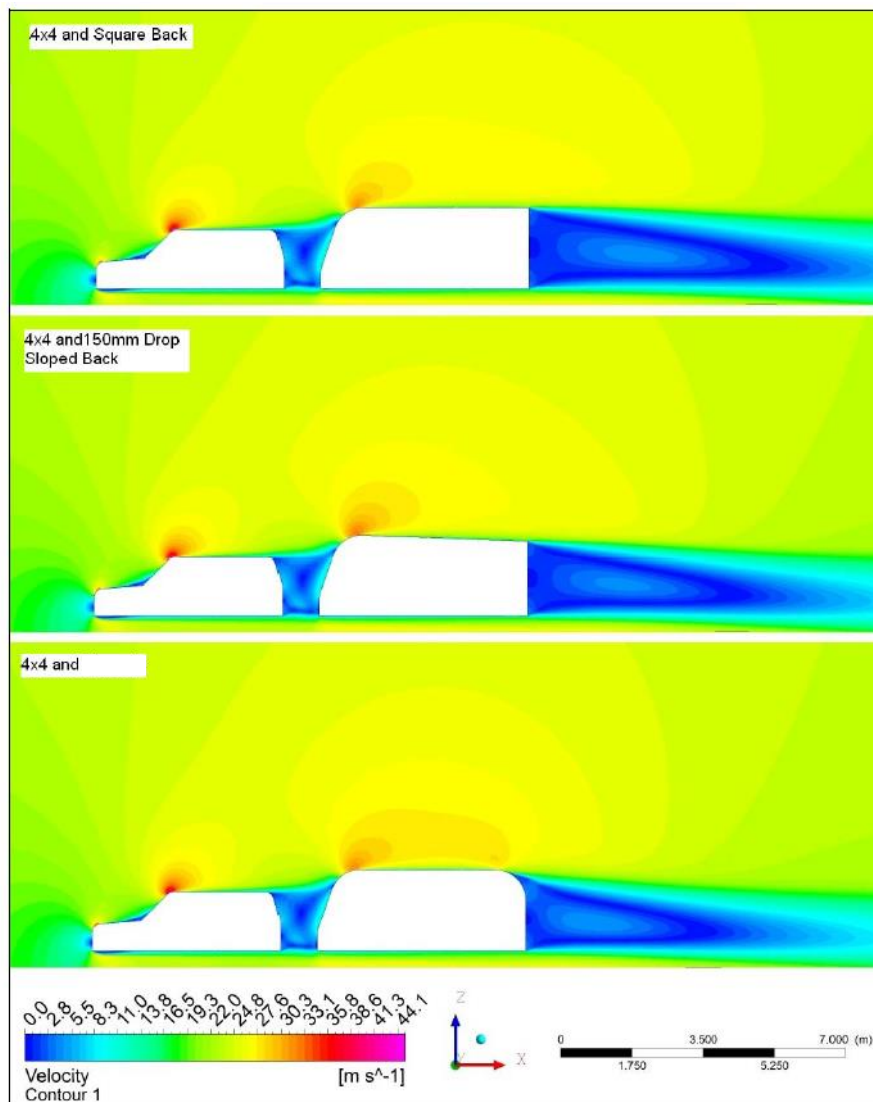


Figure 25: Study Two: Comparison of Velocity Profiles for 2D Air Flow over Caravans with a Square Back, a Sloped Top Face and Curved Rear Edge. Image taken from Berry (2010)

In this study Berry calculated that the sloped back design offered a 17% drag coefficient improvement over the square back design, while the curve back offered a 20% improvement. As the curved rear edge design maintains more head room this was seen to offer a clear advantage.

Aerodynamic Study Three – Testing Design Improvements for Further Drag Coefficient Improvements

The third study took a closer look at the air behaviour at the rear edge of the caravan, with the aim making further improving to the curved rear edge. The study focussed on the behaviour of the air around the rear curve and found that the reduction in the wake was caused by the air remaining attached to the caravan surface for longer. Measuring to the point of separation revealed that air broke from the surface of the caravan after

travelling through 20 degrees of the curve, as shown in Figure 26. To prevent separation at this point a “curve-straight” design was proposed, introducing a flat edge at the separation point. Figure 27 shows that this did achieve a further reduction in the wake area. Berry calculated that this design would offer a 39% drag improvement over the square back shape.

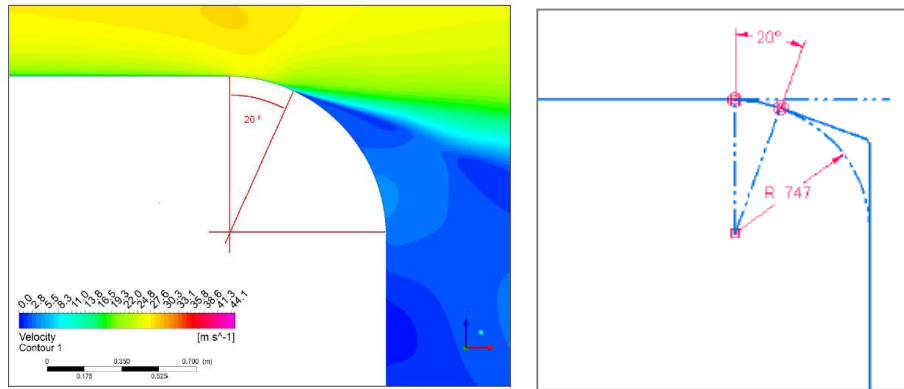


Figure 26: Study Three: Further Investigation of the 2D Air Flow Due to Rear Curve, Identification of the 20 Degree Separation Point and Suggested “Curve-Straight” Design Improvement. Images taken from Berry (2010)

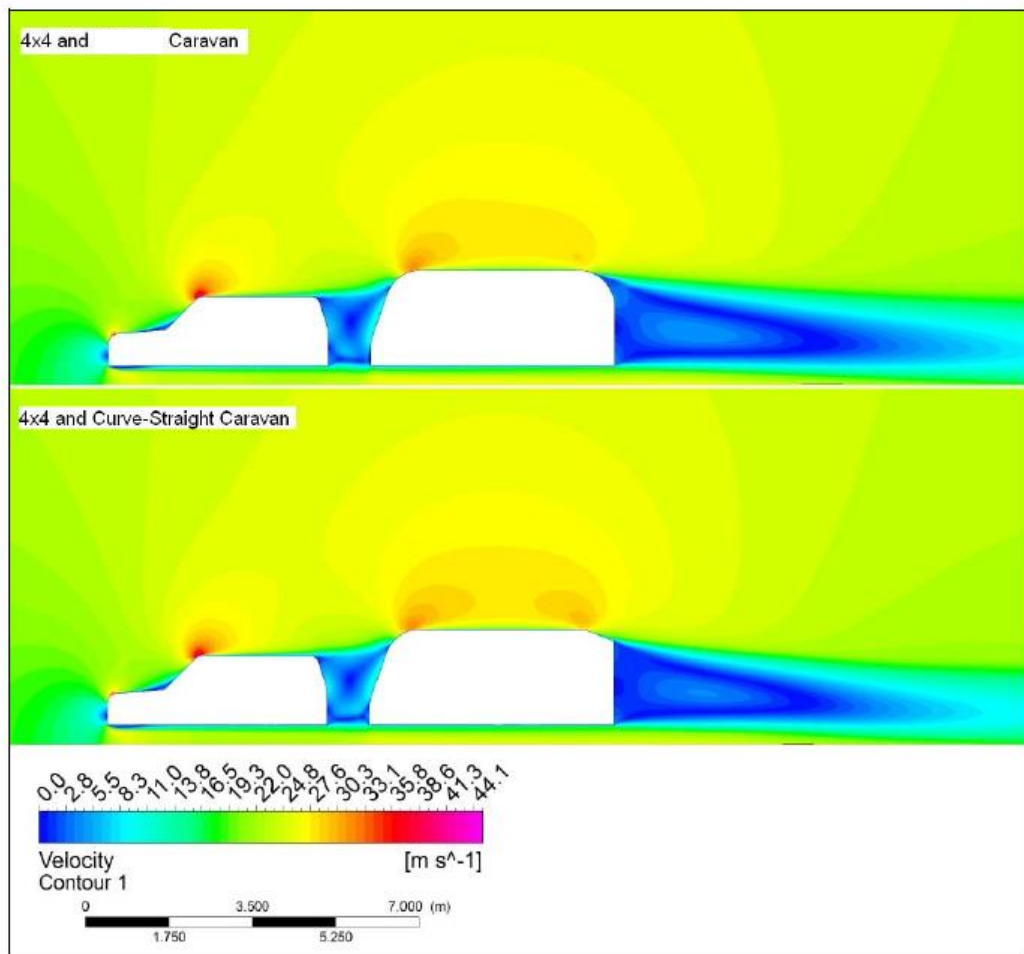


Figure 27: Study Three: 2D Velocity Contour Plots Showing the Wake Reduction of the “Curve-Straight” Caravan Profile Compared to the Curve Profile. Image taken from Berry (2010)

Aerodynamic Concept Development: Front and Rear Shape

The aerodynamic investigations had provided the team with a better understanding of the fundamental physics of aerodynamic drag, the fuel economy improvements offered by aerodynamic design, the design options available to them to reduce aerodynamic drag, and the relative improvements offered by different design options.

Using this understanding as a basis, concepts were developed with the aim of improving air flow at the front and rear. Concept 1 shown in Figure 28, proposed an extension to the straight section of the 'curve-straight' design developed by Berry, with the aim of further reducing the point of separation. The spoiler nature of the design also offered a visual identification that highlighted its aerodynamic design. The profile also restored much of the internal head room lost by the introduction of the curve.



Figure 28: Prototype of Aerodynamic Concept 1 - The Spoiler Prototype Designed to Reduce Wake by Lowering the Flow Separation Point

Concepts 2 and 3, shown in Figure 29, were developed to tackle air flow at the front of the caravan. Both concepts smoothed over the outer leading edges and reduced the space between the car and caravan. These concepts became known at the 'Nose Cone' and 'Horsebox' concepts.

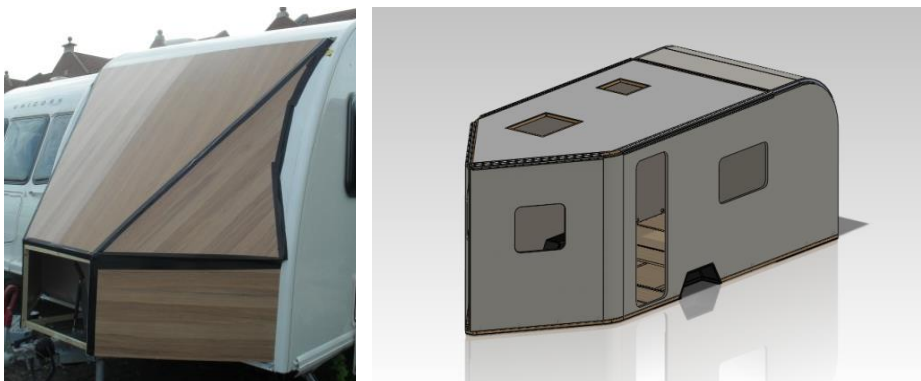


Figure 29: Aerodynamic Concepts 2 and 3 -The Nose Cone Prototype and the Horse Box Modelled in CAD.

The company were interested in these design concepts but again found them hard to evaluate without understanding the magnitude of the improvements they represented. Establishing this was difficult for a number of reasons. Firstly the company only provided limited resource for this prototyping, which limited their quality and prevented them from being road legal. This meant that fuel testing could not be conducted. Secondly the team did not have access to a wind tunnel and the cost of external aerodynamic consultancies was also found to be too high to secure investment from the company. The only option was to qualitatively observe changes in the air movement around each concept using a technique known as tuft testing (Chik, 2007).

Tuft Testing

Tuft testing is a technique that uses material tufts to visualise the air flow around a moving object. Tufts of fabric are attached to an object's surface and the movement of these tufts is captured on video as the object travels enabling air flow to be observed and analysed. While this method provides a low cost way of visualising 3D air flow at the surface of an object, it is limited by its purely qualitative nature, preventing the calculation of a numerical drag coefficient.

Air Visualisation Studies Conducted Using Tuft Testing

The goal of this tuft testing was to compare the air flow at the front and rear of both the original square back, and new curved back designs, and assess if the design concepts (Figure 28 and Figure 29) offered further improvement.

The testing used a production standard square back and curved back caravan and the concept prototypes built by the author. The company made one caravan available for prototyping and requested that any alterations were reversible to that they could re-work the caravan to production standard and sell it, once the testing was complete. The desire to sell the caravan limited the study as it prevented prototyping of any shapes that cut into the existing shape, such as the original 'curve-straight' shape proposed by Berry and the 'Horsebox' shape. As such only the Spoiler and Nose Cone concepts were tested.

To conduct this test the caravans were transported to an unused airfield runway, to allow the moving caravan to be safely filmed by another car. A grid of 12cm tufts were attached the surface of each caravan at areas of interest, spacing them far enough apart to prevent interaction. The study at the front of the caravan compared the behaviour of the air around the flat leading face of the original design, the continuously

curved leading face or the curved back design and the 'Nose Cone' concept, as shown in Figure 30.



Figure 30: The Flat, Curved and Nose Cone Designs Compared at the Front of the Caravan.

The design differences compared at the rear were the square back, the curved rear edge and the 'Spoiler' concept, as shown in Figure 31.



Figure 31: The Square, Curved and 'Spoiler' Shapes Compared at the Rear of the Caravan.

Tuft Testing Results: Flat, Curved and Nose Cone Leading Faces

Figure 32 shows the air flow over the upper and lower section of the flat leading face and continuous curve. Both show large areas of turbulent air downstream of the leading edge, with particular turbulence over the upper half. Comparing the footage of these shapes the difference in the air flow is negligible suggesting the slight curve introduced on the leading face has little impact when compared with the right angle at the leading edge.



Figure 32: Air Flow Comparison of the Upper and Lower Leading Edge of the Square Back and the Whole Leading Edge of the Curved Back Caravan Showing Negligible Differences

This finding supports the theory behind the 'Nose Cone' concept, however as Figure 33 shows the 'Nose Cone' improved the laminar flow over the lower half of the caravan but actually appeared to increase the area of turbulent air in the upper section. The results observed may be a result of the quality of the prototype or may be caused by the air being funnelled upwards by the nose cone shape. The inconclusive result prevented further design development at the front of the caravan.



Figure 33: Air Flow at the Leading Edge of the Nose Cone Prototype

Tuft Testing Results: Square Back, Curved Back and Spoiler Design

The studies at the rear of the caravan provided clearer design direction. The square back design, shown in Figure 34, produced turbulent air at the extremities, with the behaviour of the tufts revealing vortices being generated at the corners. Towards the centre of the rear face the tufts continued to hang down and remained relatively still throughout the testing revealing the low pressure wake area produced by the caravan. The air was also slow moving at the centre of both the vertical and horizontal edges. This is thought to be the result of the air having already separated from the caravan upstream of these points. This suggests that the cross sectional area of the wake may be larger than the caravan itself.



Figure 34: Air Separation at the Rear Edges of the Square Back Caravan.

The curved back study revealed some interesting 3-dimensional effects not revealed by Berry's 2D study. While the air at the outer edges seemed to support Berry's findings of a 20 degree separation point, the separation point appears to rise towards the centre of the caravan, as shown in Figure 35, producing a larger wake area than expected.



Figure 35: The Air Separation Identified at the Rear of the Curve Back Design

The Spoiler concept was proven to reduce the wake area considerably, as shown in Figure 36. It achieved this by maintaining laminar flow along the face and maintaining the lower separation point across the width of the caravan. Berry's report had found that the flat-curved design offered a 19% improvement over the curve when studied as a 2D system. These findings suggested that the Spoiler design would offer significantly larger aerodynamic improvements when compared to rear curve. Unfortunately due to the limitations of the testing this figure could not be quantified.

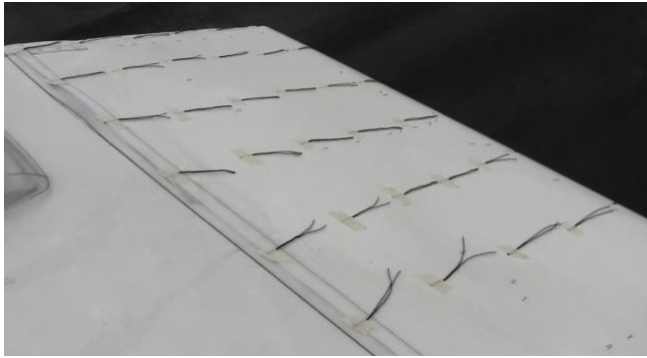


Figure 36: Air Flow over the Rear Spoiler Design Showing Uniform Laminar Flow across the Top Edge

Concept Review by KTP Team

The design concepts and aerodynamic test results were shared with the KTP team throughout the process of development and testing. The testing had enabled the team to verify that both the rear curve and spoiler design, improved aerodynamic performance. It also highlighted the negligible impact made by design changes to the front face.

The team then discussed these design concepts and reviewed them for manufacturability and user impact. What was revealed during these discussions was the company's determination to design within the confines of the current manufacturing process. Due to their recent and significant investment in the new construction system they were keen to maximise the output from the design and infrastructure. From an aerodynamic perspective this was very limiting, because this design relied upon extrusions which joined the panels at 90 or 180 degrees. As the spoiler design introduced an obtuse angle between the top and rear panels, the company did not feel that the commercial benefit of this design justified the tooling and development investment needed to create a new extrusion and the design was not progressed.

Summarising the Beneficial Outcomes and Challenges Presented by the Aerodynamic Design Development Project

The aerodynamic development project had increased the company's understanding of the subject and the impact of design changes on aerodynamic performance, however the environment within which this project was taking place also presented some significant challenges when undertaking this work. The outcomes and challenges are summarised in Table 15.

Beneficial Outcomes
- Improved understanding of the aerodynamic forces experienced by a caravan

<p>and the primary design features that contribute to a caravan's aerodynamic drag. Reports detailing both areas.</p> <ul style="list-style-type: none"> - Fuel savings made by introducing a curve to the rear edge and the percentage improvements to the drag in 2D. Providing data to support the marketing of this concept. - Qualitative analysis of key design concepts and design concepts that the company could implement in future design development. - Promotion of aerodynamic design within the industry, as shown by the core competitors studying aerodynamics in response.
<p>Key Challenges</p>
<ul style="list-style-type: none"> - The novelty of aerodynamic design required increased resource to assess the impact of design changes. - Support and resource for this project was limited as a result of the recent and significant design and manufacturing changes. - Support and resource was also limited because the company were not clear of the market appeal; no business case was presented to support these design alterations.

Table 15: The Beneficial Outcomes and Key Challenges Associated with the Aerodynamic Design Development Project

3.7.2 Reducing the Weight of the Caravan

The relationship between the weight of a car and its fuel consumption is complex and depends upon the size of the engine, the powertrain and the driving conditions. A car-caravan combination is evidently more complex due to the additional variables it introduces. Despite the difficulty of modelling the relationship between weight and the fuel consumption when towing a caravan, the industry understands the customer appeal of a lighter caravan. Cars have specific towing loads based on their gross vehicle mass (GVM) and those who caravan commonly chose their car to enable towing. Providing a lighter caravan can therefore offer significant savings as the customer is able to buy a smaller vehicle and reduce their fuel consumption both when towing and when not.

As a result of this existing interest, the company already had questions they hoped to answer during the weight study. Firstly they were keen to understand the constituent contributions made by the key design features. Secondly they wanted to understand how feature reduction impacted market appeal.

Understanding Constituent Weights within a Caravan

A study of the constituent masses within a caravan was completed to understand if any disproportionate contributions could be identified. The data needed to conduct this study was taken from the weighted bill-of-materials (BOM) developed for the LCA. The weights were grouped into four categories, representing significant areas of the

caravan and a fifth that grouped the bought in components. The constituent results were summarised and communicated to the business, as shown in Figure 37.

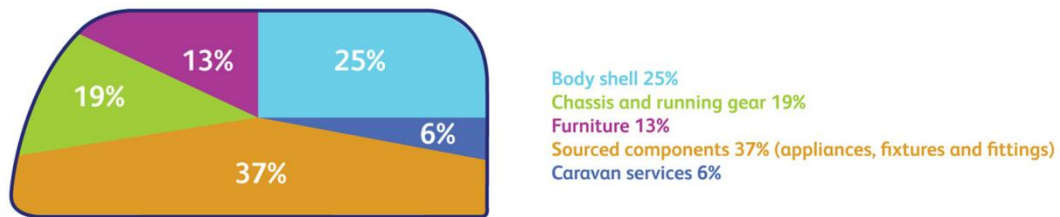


Figure 37: Constituent Weight Contributions made by Systems of Similar Material Make Up within a Caravan

The study found that the sourced (externally bought-in) components had the highest mass-to-volume ratio. Tackling the weight of the sourced components was difficult due to the size of the company relative to their supplier organisations. Due to the small size of most caravan companies, manufacturers of dedicated products such as cookers, hot water heaters and fridges, operate at multinational scales, supplying to multiple caravan producers and often have a monopoly. In this scenario the relative importance of each manufacturer reduces and request for design changes and R&D investment also weakens. Despite this, a dialogue was started with each relevant supplier, with the aim of highlighting the issue to them. Given the low volume to weight ratio of the components designed in-house, the supplier dialogue was viewed as sufficient progress.

Reducing Weight through the Removal of Functionality

The company were also interested in exploring the option of weight reduction through tailoring functionality to suit different user groups. The company had observed a segmentation in the market place prior to the KTP project. They wanted to understand the market potential of a low weight, entry level caravan whose functionality was tailored to certain market niches. The customer questionnaire developed for the in-use phase, was used to gather this data. Questions 18 and 19 of the customer questionnaire asked the customers to specify the frequency with which they had used certain appliances during their last caravan holiday. The question specified the last caravan holiday to prevent generalisations or estimations introducing bias to the responses.

Figure 38 shows the percentage of the 2,698 respondents who used appliances every day and those never used them during their last caravan holiday.

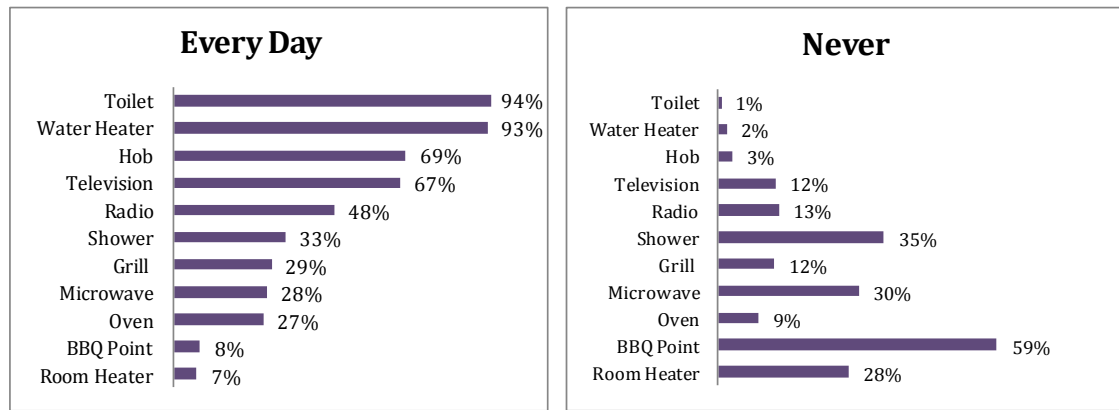


Figure 38: The Appliances Used Every Day and Never During the Customers Last Caravan Holiday

These results show that appliances such as the toilet and water heater were regularly used by all customers, whilst a sizable number of respondents did not use the BBQ point, shower or microwave. These profiles also reveal that appliance usage is not fixed within specific areas of the caravan. For example it would not be advisable to remove the bathroom from a caravan despite their being potential for removing the shower. Equally the hob is used far more regularly than the oven, so removing the cooking area would not be advised.

To incorporate these findings into design development the numbers needed to be interrogated further. To prevent the design of a product with very limited market appeal, the 35% of users who never used their shower, also had to share similar demands from the rest of their caravan and therefore be interested in purchasing the same kind of product. To assess this, the appliance use was cross referenced with the other user data such as their preference for on- or off-site holidays and the people they went on holiday with. Cross checking the responses in this way provided few commonalities between appliance use and user profile. The only groups that could be found to display common appliance use was those who stay on sites and made regular use of electrical appliances, and those who stayed offsite and avoided electricity use.

Question 17 asked customers to identify whether they used a 230V hook up (on-site use) or 12V battery (off-site) electricity supply when caravanning. The results found that 91% of the respondents stayed on-site while only 9% stayed off-site. As a result of this ratio the company felt that there was a clear market potential for an on-site, electric only caravan that offered a significant weight and cost savings over the current design.

The Electric Only Caravan Concept

An on-site only caravan has the potential to offer weight and cost savings as a result of streamlining the sources of power. Caravans typically have three energy sources that the user can choose from; 230V mains electricity, 12V battery and gas. These three energy sources enable the caravan to be fully operational when on- or off-grid. Appliances such as the water and space heaters and fridge are specifically designed to operate on any of these three power sources. What the customer survey had shown was that the majority of caravan users stayed on catered caravan sites, with a mains hook-up and were therefore towing a caravan that far exceeded their needs. The design of an electric only caravan would meet their needs which reducing cost and weight through the removal and simplification of bought in components.

The Managing Director was particularly keen on this idea as it offered caravan use without the need for a large tow car and reduced total cost of ownership, opening up a new 'entry level' market segment. To ensure that the product offering was persuasive enough to encourage customers to try this new concept, the Managing Director set a weight reduction target of 100kg and a cost reduction target of £1000 when compared with the equivalent existing model.

Designing the Electric Only Caravan

The company's current entry level caravan was used as the basis for the design. The first stage was to understand the potential of meeting the weight and cost targets specified. The weight and cost deltas were measured by manually removing and weighing all the components that would no longer be needed, from an entry level caravan. This included the triple operating mode fridge, space heater and water heater. The cost of these obsolete components was then summed to understand the saving they represented. Through this exercise a potential weight save of 95kgs and a cost save of £875 were identified. The company therefore approved ongoing development.

The next step was to source replacement parts. This was more challenging than it initially appeared as domestic appliances proved to be much heavier than those used by the caravan industry and mainstream caravan suppliers tended not to offer single power source products. In some cases this meant that alternative suppliers had to be found and new purchasing agreements had to be made. In other cases the original components had to be used. The suppliers of each of these components were met with to discuss the concept in detail. Again the relative scale of the organisation was a challenge, but all suppliers expressed a willingness to engage with the project.

The Electric Only Caravan Design Outcome

The electric only caravan concept was developed in 3D CAD, prototyped and manufactured, as shown in Figure 39. The caravan was revealed at the 2012 London Motorhome, Caravan and Camping Show, generating significant interest and discussion amongst the caravan press.

The customer response was mixed due to the appeal of the weight and cost savings and nervousness around the potential limitations as a result of its functionality. The show did however provide some valuable insights into the areas of improvement needed to increase the products market appeal. The prototype had proven the market potential of the idea.

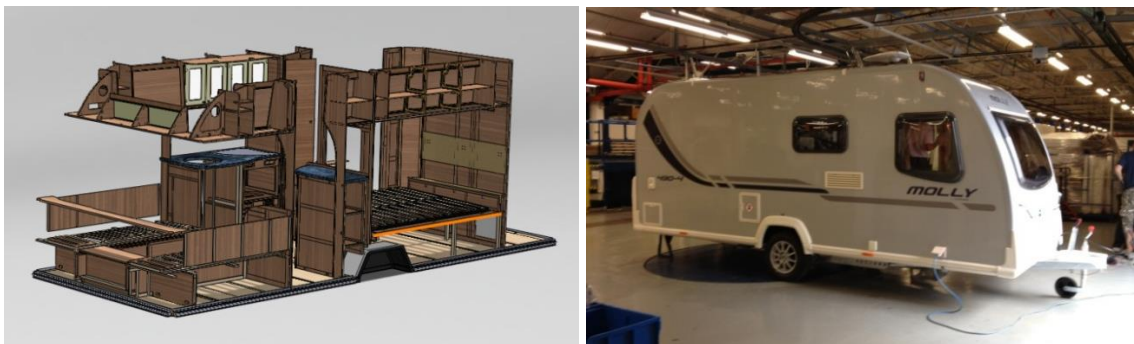


Figure 39: The Electric Only Caravan Developed as Part of the KTP Project shown in 3D CAD and as a Prototype

Summarising the Outcomes of the Weight Reduction Design Development

The weight reduction project was highly beneficial for the company who were able to market test a longstanding design concept. Despite the relative ease of this development compared with the aerodynamic development, the introduction of a new concept still faced challenges. A full summary of the beneficial outcomes and challenges presented by the weight reduction project is given in Table 16.

Beneficial Outcomes
<ul style="list-style-type: none">- A mass study that broke down constituent weights into identifiable groups and identification of the key weight down opportunities.- A market study detailing the appliance use of caravan customers and identification of the market potential for an electric only caravan.- Design development, manufacture and market tested of an electric only caravan concept and the identification of improvement areas to support further development.- Increased confidence in the market appeal of low weight caravan design and increased focus on the issue throughout the company's technical team.- Clear next steps for further product development of the low weight caravan concept.

<ul style="list-style-type: none"> - Engagement with the supply chain over potential weight reduction ideas.
Key Challenges
<ul style="list-style-type: none"> - Understanding and establishing the right market positioning for an environmentally improved product offering. - The availability of alternative products and capability of the supply chain in supporting the new product offering. - The company's ability to affect change within their supply base.

Table 16: The Beneficial Outcomes and Key Challenges Associated with the Weight Reduction Project

3.7.3 Reducing Tyre Rolling Resistance

Rolling resistance contributes to the total fuel consumption of a vehicle as a result of the visco-elastic behaviour of rubber. As the wheel turns the rubber repeatedly deforms and returns to shape. While the elastic nature of rubber causes the tyre returns to its original shape, the viscous properties cause some energy to be lost as heat. As a result the vehicle has to generate more mechanical energy to overcome the energy loss and maintain the same speed (Stein et al., 2006)

The loss of mechanical energy is called hysteresis and its magnitude results from various tyre properties and operating factors. These include the tyre design (tread depth, wall thickness, tyre width, ply construction), the chemical composition of the tyre (material mixes and quantities), the tyre loading (mass being applied to the tyre as it deforms) and the tyre inflation (Stein et al., 2006).

Despite numerous studies into the impact of rolling resistance on vehicle fuel consumption, no studies were found into the additional rolling resistance experienced when towing a caravan. The general rule of thumb for passenger vehicles is that rolling resistance consumes one third of the mechanical energy applied to turn the wheels. Reducing a vehicle tyres rolling resistance coefficient by 0.001, will result in a 1-2% increase in fuel economy (Stein et al., 2006). Although understanding the exact relationship for caravan tyres was outside of the scope of this study, these figures indicate a significant impact over the life time of the caravan.

Although the relationship between rolling resistance and towing fuel consumption could not be quantified, lower rolling resistance tyres were available on the market, making this an apparently easy win for the company. These tyres are typically produced by adding silica to the tread compound (Rauline, 1993) and/or changing the oils used in the tire compound and are commonplace in the automotive industry. The challenge was to find suitable low rolling resistance tyres for this application. Due to the large amount of time caravans spend stationary their tyres have specific design conditions to

ensure durability and as such caravan tyres are designed specifically for this application. These are produced by global tyre manufacturers in relatively small numbers and none of the major manufacturers were producing low rolling resistance options. In this scenario the company found that again their size relative to that of the suppliers gave them limited power when escalating their requests. Discussion with the company who supplied the current tyres were held and the supplier showed interest in the idea, however they needed higher volume sales than the Company could guarantee, before putting in a formal R&D request to the manufacturers.

Another key challenge was that the rolling resistance of the current tyres was not known, preventing the company from being able to judge alternatives against this metric. Visits to a vehicle tyre research centre were made and the low rolling resistance and lower environmental impact tyres were explained. The cost of establishing the current rolling resistance was also investigated with this team, however the supplier then suggested that the company wait until the impending EU tyre labelling legislation (EC No.1222/2009) was introduced. The legislation, which came into force in July 2012, requires all new tyres to be marked with their energy efficiency (measured according to rolling resistance), grip in wet conditions and external noise. It was decided to review the tyre specification when this information was freely available and postpone further development until this point.

Summarising the Outcomes of the Rolling Resistance Project

Although the rolling resistance project was postponed it still provided new knowledge and promoted the engagement of suppliers when tackling current environmental impacts. A list of all beneficial outcomes and challenges presented by the rolling resistance project is given in Table 17.

The Beneficial Outcomes of the Rolling Resistance Project
<ul style="list-style-type: none"> - Awareness of future legislation changes relating to tyre rolling resistance. - Improved understanding and awareness of the impact of rolling resistance within the company's technical team. - Strengthened relationship with supply chain and communicated desire to achieve lower rolling resistance.
The Key Challenges Faced when Undertaking the Rolling Resistance Project
<ul style="list-style-type: none"> - The company's ability to affect change within their supply base. - The novelty of the requests made by the Company to the supply chain and the limited availability of information to support these requests. - The availability of environmentally improved alternatives.

Table 17: The Beneficial Outcomes and Key Challenges Associated with the Low Rolling Resistance Tyre Project

3.7.4 Reducing the Use of High Embodied Energy Materials

The data collection undertaken to model the materials phase of the LCA identified the significant contribution made by the high use of aluminium. Prior to the start of the KTP project the company had considered using external glass reinforced plastic (GRP) rather than sheet aluminium, for the outer layer of the caravan body. GRP offered a weight saving and, as it was not easily chipped, it also improved the quality of the product. Having completed the LCA, the company were also keen to understand the environmental impact that this design change would make. This would signify the first time that the company had attempted to incorporate environmental information into their design decision making process. The Associate therefore gathered information relating to the environmental impact of the two materials, and geometric information relating to the use of these materials, within the design. The data collected revealed that the GRP had a lower embodied energy than aluminium and that its use would reduce the overall weight of the caravan by ~3.5kgs, as shown in Table 18, resulting in a reduction in both the materials and in-use phases.

External Material	Embodied Energy (MJ)	CO ₂ E-eq (kgCO ₂ E)	Mass of Aluminium in Caravan (kg)	Mass of GRP in Caravan (kg)	Mass Change due to GRP
Aluminium Sheet	155	8.24	158.31	59.74	0
External Grade GRP	100	8.1	95.65	118.94	-3.46kg

Table 18: Energy, Emissions and Density Comparison of Aluminium vs External Grade GRP

In order to meaningfully communicate and promote this improvement both internally and externally, the exact environmental impact of the design change needed to be calculated. While the impact on the materials phase could be quite easily calculated from the data shown in Table 18, the original in-use phase had been calculated using average fuel consumption figures from consumers. As such the business had no understanding of the relationship between the weight of the caravan and the fuel consumption of the car, and could not therefore assess the impact of small weight reductions. While a 3.4kg saving is unlikely to yield large CO₂ savings, the relative contribution made by the use phase makes any weight saving significant.

In the absence of an in-use phase impact, the materials phase impact was calculated per caravan and for all caravans produced in one year, as shown in Table 19. This was presented to the technical team in support of a change to GRP. The first caravan to use external grade GRP was the low weight electric caravan.

	Embodied Energy of Aluminium and GRP (MJ)	CO₂E-eq of Aluminium and GRP (kgCO₂E)
Aluminium Sheet	30522	1785
External GRP	26720	1751
Embodied Energy Reduction per Caravan (GRP vs Aluminium)	- 3802	- 34
Annual Embodied Energy Reduction (x9000)	34,218,000	306,000

Table 19: Energy and Emissions Deltas Calculated when Using External GRP in Place of Sheet Aluminium

Similar to the rolling resistance project, this example highlights how the environmental focus was posing new questions, but this time these questions were aimed at the company themselves. The lifecycle assessment demanded a new perspective on the product and the company did not have the level of understanding required. Importantly they also didn't have the resource within this project, nor did they have the commercial motivation to find the additional resource needed to achieve this level of understanding.

Summarising the Outcomes of the Embodied Energy Project

The embodied energy project had given the company their first experience of incorporating environmental information into the design decision making process. It also exemplified how each design decision impacts the products environmental performance, making this a very valuable exercise. The project had however highlighted some challenges in the LCA process. A full summary of beneficial outcomes and key challenges is given in Table 20.

The Beneficial Outcomes of the Embodied Energy Project
<ul style="list-style-type: none"> - Experience of incorporating environmental information within design decision making. - Quantitative comparison between the materials phase of a caravan when using an aluminium external face vs glass reinforced plastic. - Improved awareness of the limitations of the current lifecycle understanding

within the company.
The Key Challenges Presented by the Embodied Energy Project
<ul style="list-style-type: none"> - Obtaining the data needed to model the life cycle impacts of the material change.

Table 20: The Beneficial Outcomes and Key Challenges Associated with the Low Embodied Energy Project

3.8 Summarising the Introductory Eco-design Case Study

The following section summarises the introductory eco-design case study. The summary has been split into three sections; the activities, achievements and challenges. The final section pulls together the learning outcomes from each.

3.8.1 The KTP Project Activities

The work completed during the KTP project can be summarised into ten product development activities as shown in the Table 21. These project activities include the introduction of the lifecycle inventory process and the application of traditional product research activities, such as the completion of a customer survey, focussed on development of new environmental knowledge. The activities described, closely match the stages defined in the original project proposal, shown in Figure 17.

Activities Conducted During the KTP Project
<ol style="list-style-type: none"> 1. Streamlined LCA conducted on a representative, mid-range product. 2. Completion of a customer questionnaire focused on the product's use phase. 3. Defined environmental improvement goals based on the outcomes of the sLCA. 4. Conducted research and development activities addressing each improvement goal. 5. Developed product concepts and prototypes. 6. Conducted product testing and refined concepts. 7. Presented concepts to product development team and refined design. 8. Detailed design and Computer-Aided-Design (CAD) model production. 9. Supported first production run and refined design. 10. Supported product launch and media outreach.

Table 21: The Design Development Activities Conducted during the Eco-design Focussed KTP Project

Importantly these activities can also be seen to follow the stages of the Total Design Process as defined by Pugh (1991), shown in Figure 10. The difference between the process defined by Pugh and the process of eco-design introduction described here is the environmental focus of the inputs. For example where Pugh discusses material inputs, the KTP project was concerned with the assessment and identification of environmentally improved materials. What this case study shows, is that making these adaptations throughout the product development process provides a wealth of

development opportunities, however it also introduces significant challenges in the nascent phase, due to the novelty of the subjects being developed. To exemplify this point the following sections describe the areas of development and the challenges faced during this project. The examination provides some interesting insights into the introduction of eco-design within this industrial context.

3.8.2 The Areas of Development achieved during the Introductory Eco-design KTP

A summary of the five key areas of development achieved during the KTP are shown in Table 22. Specific examples of each area of development are selected from the case study and used to establish a general description.

Areas of Development for the Company	Examples of Development at the Company	Description of Development in General Terms
Product Knowledge Growth	<ul style="list-style-type: none"> - Quantitative data describing the material break down of the product - Greater awareness of the supply chain (transportation phase) - Identification of future legislation impacting the product (tyres) 	Conducting the LCA and addressing environmental impacts, required a much deeper level of knowledge about every stage of the product's development. The outcome was a greater awareness of their product and business.
Environmental Design Knowledge Growth	<ul style="list-style-type: none"> - Introduction to the LCA process - Identification of the products environmental hotspots - Outcomes of the aerodynamic, weight rolling resistance, embodied energy projects - Clear next steps for the development of the LCA process - Clear next steps for the development of the low weight design concept. 	The company had no experience of environmental product design or the environmental impacts of their product. The project exemplified the LCA process, identified environmental hotspots and closely examined design development areas to address hotspots.
Customer Knowledge Growth	<ul style="list-style-type: none"> - Quantitative data provided by the large customer questionnaire. - Improved understanding of the customers interest in low weight design 	The company's customer knowledge was tacitly stored by those who had been in the business long enough. The quantitative data required to model the use phase provided

	<ul style="list-style-type: none"> - Clear next steps for improving the market appeal of the low weight design concept 	their first formal analysis of the customer and their use of the product. From this they identified some new market opportunities.
Collaboration with Supply Chain	<ul style="list-style-type: none"> - Communication required to support material and supply chain gathering - Engagement with suppliers over weight reduction project - Collaboration with suppliers when tackling rolling resistance 	The company had a commercial and collaborative relationship with most of its suppliers. The work conducted in this project enhanced the collaborative nature of the relationship with many suppliers.
Market Impact and Competitiveness	<ul style="list-style-type: none"> - Market test of first electric only caravan. - Competitors studying and altering their design for improved aerodynamic performance. Potential for first mover advantage. 	Environmental design was new to the industry. As such, the work that was undertaken in this project received significant attention from the media and from competitors. Competitors were even found to be tackling these issues in their designs.

Table 22: A Summary of the Achievements made by the Introductory Eco-design KTP

As shown in Table 22 the first eco-design project provided significant knowledge development in many areas. As the company had no prior environmental design knowledge, every stage of the project required new data and the learning gradient was steep. Interestingly, the large amount of knowledge development needed provided benefits that went way beyond the company's environmental performance. Reflecting on the knowledge generated, the product outcome offered more by way of learning, than commercial benefit. Importantly however, the project provided some clear next steps for continued process and product development.

3.8.3 Summarising the Challenges Experienced during the Introductory Eco-design KTP

A summary of the challenges experienced during the introductory eco-design KTP are shown in Table 23.

Key Challenge Areas	Examples of Specific Challenges Encountered during the Case Study	General Description of the Challenge
Novel Data Requirements	<ul style="list-style-type: none"> - Suppliers nervous about providing material information. - Difficulty of obtaining in-use 	As this was the first time that anyone in the industry had focussed on environmental design and conducted an LCA,

	<ul style="list-style-type: none"> - data required to develop a repeatable LCA model - High levels of data needed to support aerodynamic development. 	the data needed to support the project was more difficult to obtain for varied reasons. As such, increased resource was needed throughout.
Novel Supply Chain Requirements	<ul style="list-style-type: none"> - Limited availability of electric only appliances for the electric only caravan. - No low rolling resistance tyres for caravans. 	Again due to this being the first environmental product, the availability of environmental alternatives was limited.
Low Understanding of the Market Appeal or Business Case	<ul style="list-style-type: none"> - Nervousness about the market appeal of aerodynamic design. - Product positioning of the electric only caravan. 	Throughout the project the novelty of the subject acted as a barrier as the company were not clear of the business case or market appeal of an environmentally improved product. As a result, resource and engagement was often limited. Product positioning was also a challenge.
Company Capability to Affect Change	<ul style="list-style-type: none"> - Inability to make major aerodynamic product changes due to recent design and manufacturing development. - Challenge of asking suppliers to develop new products, due to size of company and isolated nature of the requests within the industry. 	At many points during the project the company's ability to make the changes needed to address environmental aspects was a challenge.

Table 23: A Summary of Challenges Faced during the Introductory Eco-design KTP

The challenges identified in Table 23 reveal the practical and psychological barriers presented by the steep and novel learning curve. The novelty of environmental development throughout the *industry* restricted the availability of information and product alternatives and reduced the ability to request changes in the supply chain due to their relative rarity. As a consequence the project often had to focus on establishing a basis upon which further development could take place, starting conversations with suppliers for example, rather than making the required product changes. The lack of clarity around the market appeal and business case for environmental improvements is also revealed as an important challenge. Without understanding the real commercial drivers for this work, the resource and motivation to overcome these challenges was often limited.

3.9 Summarising the Key Learning Outcomes of the Case Study Description

Two key learning outcomes are identified from this case study description. The first relates to the specific opportunities and challenges faced by a company in the nascent stages of eco-design development. The second learning outcome relate to the environmental improvements made through the application of an environmentally focussed product development process. Both are described in detail below.

The case study description provides important insights into the practical and psychological opportunities and challenges identified when introducing eco-design within this industrial context. During its lifetime the project provided the opportunity for knowledge development in a broad range of subjects and promoted eco-design through its ability to strengthen supply chain relationships and improve competitiveness. The challenges included managing the novelty of the topic internally and externally, the scale of knowledge development needed internally and externally, a poor understanding of the business drivers for eco-design for this new area of development and the company's ability to affect change within the supply chain.

The case study also described the development and market testing of an environmentally improved product concept, confirming that the application of an eco-design product development process is able to achieve significant environmental product improvements. The first prototype needed further development; however these development areas offered some clear next steps for the company.

3.10 Ongoing Development following the KTP Project's Completion

The previous section has shown how the KTP project provided learning and identified some key next steps for environmental development at the company. Following the KTP project's completion the author continued to work with the company for a further 3 months. During this time there was a strong sense that the project was now done and that, with the removal of the KTP structure, there was not the resource or motivation to continue eco-design development. Although the KTP had identified next steps, no formal plan had been developed for the continuation of eco-design and despite efforts by the KTP Associate the company showed no interest in the development of guidance or tools to support further work. Despite the large amount of work undertaken and the knowledge and design development achieved, these actions suggest that the project had not motivated the company towards ongoing eco-design development.

Given that the KTP project lasted for two years and received financial support from both the company and the Technology Strategy Board, the lack of motivation for continued progress brings its effectiveness into question. This observation identifies the third learning outcome for the introductory case study description; the dual role that the introductory eco-design project must play. The first eco-design project must do two things; it must increase the company's knowledge and understanding of eco-design, and it must promote and support ongoing development. While this is particularly true in the case study scenario where support for eco-design development is temporary, these are clearly important goals for any first eco-design project looking to move past the pilot project stage.

With this learning outcome in mind a retrospective analysis of the case study was developed. The aim of this analysis was to examine the impact of the KTP project in the longer term and assess its apparent inability to motivate or supporting ongoing eco-design.

4. A Retrospective Review of the Introductory Eco-design Case Study

The previous chapter described the introduction of eco-design within a company with no prior experience, and defined the role of the first eco-design project as one that introduces the practice whilst promoting and supporting ongoing development. In this chapter the long term impacts of the KTP project are examined to meet the second objective of this research.

Objective 2: Taking a longitudinal perspective, assess the impact of introductory eco-design activities in the longer term and their ability to motivate and support ongoing eco-design development.

To meet this objective, the introductory eco-design case study has retrospectively reviewed. The review consisted of three research activities. To begin, retrospective interviews were held with the Company's Managing and Technical Directors two years after the project's completion. Adopting an inductive approach, the interview transcripts were analysed, allowing the identification of patterns in the data and the emergence of a preliminary theory. The second research activity involved the analysis of real time project documentation including meeting minutes, presentations and reports. Finally the company's subsequent product design alternations were assessed through publically available websites and product launch documentation, to help support the longitudinal view of the project impacts.

4.1 The Retrospective Review Objectives

As described the retrospective interviews were developed to meet Objective 2. To help structure the interviews and develop the research questions, the core research objective was broken down into three retrospective review objectives, as shown in Figure 40.

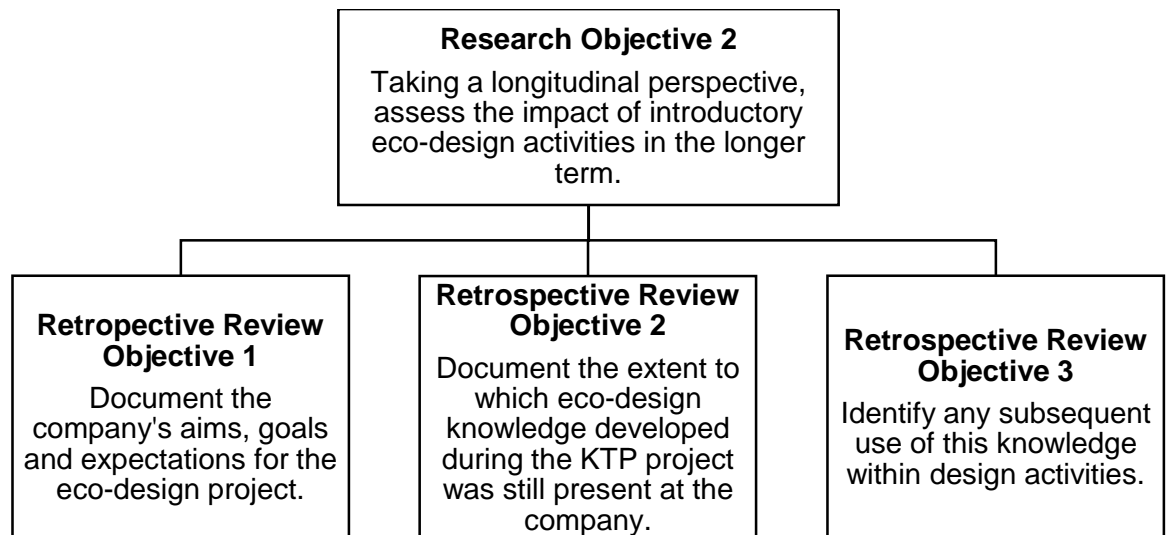


Figure 40: Interview Objectives Identified to Address Research Objective

The retrospective review objectives were developed to structure the review, but also to aid the development of the interview questions.

Retrospective Review Objective 1 – The first retrospective review objective was identified to discuss the aims, goals and expectations, that the Company had for the project. This objective was identified to understand how the company view had impacted the activities and shaped the outcomes. As the interviews were conducted two years after the project's completion, these questions also provided the opportunity to talk through the project and remind the interviewee of its content.

Retrospective Review Objective 2 - The second retrospective review objective aimed to identify and characterise the knowledge that had been retained within the Company. Understanding the areas of knowledge that were actively present at the Company, helped characterise the knowledge that the company deemed relevant and assess where knowledge transfer had succeeded and failed.

Retrospective Review Objective 3 - The third and final objective was identified to help characterise the way in which the Company had integrated the relevant and successfully transferred knowledge within their design development process.

4.2 The Retrospective Interviews

The aim of the interviews was to gather as much information about subsequent activities at the company as possible, without influencing their responses or making the interviewees feel they were being examined or tested. As the interviews were a discussion of the interviewers work, the inherent impact of the interviewer's presence is

acknowledged. To minimise this impact a Standardised Open-Ended interview (Turner, 2010) was developed. Standardised Open-Ended interviews were chosen as they allow *“the participants to contribute as much detailed information as they desire”*, whilst also allowing *“the researcher to ask more probing questions as a means of a follow-up”*. This approach enables the researcher to structure the interview to ensure that objectives are met, whilst also providing the flexibility to explore unexpected avenues. The inherent challenge of this approach comes from the wealth of data it provides, making analysis more cumbersome. However, due to the low number of interviewees, this was deemed to be manageable.

To ensure that the interview encouraged a full and open exploration of the manager’s views, the questions were developed using the following guidelines summarised from (McNamara, 2009) and (Weiss and Bolton, 2000):

1. Wording should be open-ended – questions that allow the respondent to answer without presented or implied choices;
2. Questions should be as neutral as possible (avoid wording that might influence answers, e.g., evocative, judgmental wording);
3. Avoid leading questions that are phrased to suggest a particular answer or to imply that one answer is expected or more correct;
4. Questions should be worded clearly;
5. Be careful asking "why" questions as it can imply that there is a factual answer. Leading interviewees to try and give the ‘right’ answer.

The interview questions (which can be seen in full in Appendix 3) are shown in Figure 41.

The Retrospective Interview Questions
<p>Q1. Can you tell me about how the KTP project came about?</p> <p>Q2. What were your expectations, aims and goals for the KTP project?</p> <p>Q3. How did this KTP project fit into your wider business objectives?</p> <p>Q4. Please can you talk about the extent to which your expectations, aims and goals were met by this project?</p> <p>Q5. Please discuss the extent to which the KTP project transferred knowledge to the company?</p>

- Q6. What were the key learning outcomes for the company?
- Q7. The KTP project resulted in the development of the electric only caravan. What is your view of this project outcome?
- Q8. How do you view environmental improvement initiatives and their relevance to your business today?
- Q9. Referring to eco-design specifically how do you view this and its relevance to your business today?

Figure 41: The Retrospective Interview Research Questions

The interviews were conducted during one visit to the Company and were recorded throughout. These recordings were then transcribed to enable careful analysis of the Director's responses.

4.3 Meeting the Retrospective Review Objectives

As previously described the retrospective review consisted of three activities; the analysis of the retrospective interview transcripts, the review of real-time project documentation, and the review of publically available product launch information. The findings of all three activities are collated to meet the retrospective review objectives. Appendix 4 provides a full list of the reference material used in this review and each has been given a reference code. The reference code is used in this chapter to identify the source. The reader is encouraged to reference this list as they read through the remainder of this Chapter.

4.3.1 Objective 1: Document the company's aims, goals and expectations for the KTP project.

During the retrospective interview the Managing Director's (MD) was very clear on his aims and expectations of the KTP project:

"I wanted to learn more about reducing weight and quantifying what an eco-product was. We wanted a greater understanding of what quantifies an eco-product and how we can make ours more eco-friendly." (Ref. Code 26)

These two goals, weight reduction and environmental knowledge development, are continually referenced throughout the interview. Reviewing meeting minutes also reveals multiple references to these aims, during the project. In the first monthly meeting, the MD noted that the environmental knowledge gained by the LCI process would be *"used for marketing purposes"* and that *"the in-use phase was of most interest"* due to the marketing benefit it offered (Ref. Code 04). In the 2nd monthly meeting, the MD provided detail of his aim for weight reduction, stating that the aim

was to realise the potential to “make a 130kg saving and that the goal was to drop a [tow] car size”. The target for the project was to design a caravan that was “able to be towed by a Ford Focus”. (Ref. Code 05)

What is notable about these aims and expectations is that they do not directly align with those defined in the KTP project plan (Ref. Code 03 and detailed in Section 3.3). While the Company were focussed on weight reduction and improved environmental knowledge to support marketing, the KTP project aimed to transfer eco-design knowledge and develop an environmentally improved design, which addressed the results of a streamlined lifecycle assessment. Although not completely contradictory there are some subtle, and important differences between these aims. Firstly, the KTP project aimed to improve all, or any, life cycle impacts, while the Company were looking to improve their environmental performance through weight reduction. Secondly, the KTP project took guidance for the outcomes of the LCI process, while the Company were driven by potential marketing benefits. As shown in Table 24, extracts from meeting minutes during discussions on weight reduction and aerodynamic improvement, reveal how these disparities affected the project activities.

Company Extracts from Meeting Minutes during the KTP Project	
Weight Reduction	Aerodynamic Improvements
<i>[The Company] noted that in order to achieve a mains only caravan a smart control panel would be needed to prioritise appliance use. (Ref. Code 15)</i>	<i>[The Company] highlighted that the introduction of an external radius [for aerodynamic improvement] would impact the design of the internal furniture. (Ref. Code 04)</i>
<i>The reduce weight caravan was estimated to save £600. [The Company] were unsure if this would be enough of a draw for the consumer. [The Company] concluded that the numbers support the development and build of the prototype. (Ref. Code 20)</i>	<i>[The Company] were concerned that the nose cone design would require the A-frame to be lengthened. (Ref. Code 21)</i>
<i>[The Company] confirmed that [a company who are not current suppliers] provide electric only fridges for boats and asked that the KTP associate looks into getting one. (Ref. Code 14)</i>	<i>The straight-flat design was not seen as being suitable for production as the introduction of an obtuse angle between the two faces would require the development of a new external extrusion. (Ref. Code 23)</i>

Table 24: Comparing Company Extracts from Meeting Minutes when Discussing Weight Reduction and Aerodynamic Improvement

What Table 24 shows, is the proactive approach the Company took in pursuit of weight reduction and the increased willingness with which they tackled design and process changes when addressing this topic. In contrast aerodynamic development was challenged at every stage. Further analysis of the interview transcripts and meeting minutes, revealed the significantly different business drivers for each topic. A comparison of the drivers is shown in Table 25.

Drivers for Weight Reduction	
Extract	Source
<i>“Every tow car is getting lighter, every manufacturer. Cars are promoting weight reduction at their product launches, so if we want to have a market we’ve got to make it lighter.”</i>	Ref. Code 26
<i>“When they bought in all these Euro limits on emissions, weight reduction become important in the automotive industry. I don’t think weight reduction is going to be driven by fuel prices, I think it’s just going to be Euro legislation. All the way through now people have to have smaller, lighter, more eco tow vehicles.”</i>	Ref. Code 26
<i>“The last time weight was really important was during the fuel crises back in the 60s and we know that came and went. This isn’t going to go.”</i>	Ref. Code 26
<i>[The MD] noted that the customers at [a recent caravan] show were enthusiastic about [the smallest caravan in the range] due to its low weight.</i>	Ref. Code 18
Drivers for Aerodynamic Improvement	
Extract	Source
<i>[The Company] confirmed that customers were achieving up to 6 miles more per gallon when towing the new caravan construction, due to the improved aerodynamics.</i>	Ref. Code 04
<i>[The Company] noted that other companies have built aerodynamic caravans, but that they were no cheaper than a larger more comfortable caravan and therefore not good sellers.</i>	Ref. Code 10
<i>[The Company] asked how we could determine what fuel saving [the nose cone design] would offer.</i>	Ref. Code 21

Table 25: Comparing the Drivers for Weight and Aerodynamic Design Development

The most notable aspect of this comparison is the imperative nature of the business drivers for weight reduction, compared with the uncertain market appeal and customer benefits offered by aerodynamic improvement. The comparison provides a clear explanation of the differing approaches taken by the Company during the project.

Despite this, both topics were given equal attention during the KTP as a result of the LCI. The KTP project plan included no activities aimed at understanding and explicitly documenting the existing drivers or weighting the life cycle inventory outcomes to align with the Company focus (Ref. Code 03). As a result the importance and relevance of design efforts could not be assessed.

The aims, objectives and text collated above also revealed that the Company understood eco-design as a series of product alterations that supported traditional design drivers and enhanced existing customer appeal. The aims and objectives do not display any understanding of the organisational impacts of mature eco-design or the potential when of the topic when addressed strategically. The retrospective nature of this review reveals that this remained true even after the KTP project's completion. Reviewing the activities within the KTP project plan, shows total focus on the achievement of an environmentally improved product, with only limited consideration of the wider business context (Ref. Code 03). While the appeal of environmental product improvements is evident, failure to address the nascent view of eco-design, impacted the project in two ways. Firstly it did not facilitate a full understanding of eco-design and therefore did not promote the potential of the topic. Secondly it prevented the development of a KTP project plan that reflected the context within which it was taking place. The aim to achieve a product design that could be used for all future models from 2012 onwards, despite the nascent stage of the company and its supply chain, is evidence of this. The Technical Director describes a greater awareness of the barriers of this nascence, as a result of the project.

"The biggest problem is that all the [alternative] products that you want to use are so expensive. They are not manufactured in enough volume, so you can't use them until you can get the price down." (Ref. Code 27)

The narrow product development focus also encouraged the development of a project that was disconnected from the core product development focus. As described in Chapter 3 this disconnection was intentionally introduced to provide the time, space and freedom to research and develop the new, environmentally improved concept. Evidently this approach supported the development of environmental product improvements (Ref. Code 24); however the retrospective interview reveals the impact this had on the Company's ongoing development of eco-design.

“We had [a supplier] in the other day and they were talking about your project and talking about the potential of developing something in line with what you were doing.” (Ref. Code 26)

“Even though we weren’t working with you all the time, we knew what you were working on. We learnt by hearing what you were talking about and seeing brochures on your desk.” (Ref. Code 27)

Viewing the project as belonging to the Associate is clearly damaging to the Company's ongoing development. When considered in these terms, it is clear why the author observed low levels of motivation towards continued development following the project's completion.

The review conducted to address this retrospective review objective, has revealed that the KTP project failed to address certain aspects of the existing business context within which it was entering. As a result, the KTP project was found to have differing aims, expectations and drivers for development that reduced the Company's engagement and support for certain design activities. The lack of a business-wide perspective also introduced a narrow product development focus that prevented exploration of the scope and business potential of eco-design and poorly reflect the inherent challenges of addressing this topic when being the first in an industry to address this topic. Instead the project applied a self-contained product development process that acted independently from the day-to-day development at the Company. While this enabled the achievement of some significant product developments, the review shows that the project activities did little to support or motivate the Company towards ongoing and independent activity.

4.3.2 Objective 2: Document the extent to which eco-design knowledge developed during the KTP project is still present at the company.

During the retrospective interview the MD discussed the environmental product life cycle with confidence throughout. He described the full life cycle on several occasions and regularly linked design changes with their impact on individual life cycle phases.

“It comes from all the different areas that [the KTP Associate] looked at in terms of material, material procurement, what we do here as an operation in terms of are energy usage, assembly, and then also the weight and towing characteristics in order to get a smaller tow vehicle, to get more MPG, less CO₂ emissions when towing.” (Ref. Code 26)

On several occasions he went beyond the information developed during the life cycle assessment, making a broader assessment of the product's impacts, showing independent thought and inferring engagement with the subject:

"The big thing is actually when they're not towing. And they're still driving that [4x4] car for commuting, for shopping, for school runs." (Ref. Code 26)

Although tending to be more practical rather than strategic, reflecting the nature of the role, the Technical Director also exemplifies an improved understanding of the products environmental impacts and the design solutions available.

"We've been carrying through the whole idea of eco-design, trying to make the caravans lighters...putting the curve on the rear. That was a surprise for us. Everyone keeps thinking that the front should be aerodynamic but we know it is not [as important]." (Ref. Code 27)

As the Company had no prior knowledge of the environmental product lifecycle these quotes clearly refer to knowledge developed during the project. What is notable about these interviews is that although both Directors discuss environmental life cycle reductions, neither makes any reference to the process of life cycle assessment. Reviewing the meeting minutes, reports and presentations produced during the project, reveals that although the LCI data collection and LCI outcomes were discussed with both Directors in depth (Ref. Codes 04, 05, 06, 07, 09, 10, 25), no focussed training or knowledge transfer activities were conducted to ensure a full understanding of the process. This evidently limits the Company's ability to undertake independent eco-design development, as they have no knowledge of how to repeat the LCI process. As their product design progresses and the outcomes of this first LCI become less relevant, the Company would need to seek further external support to conduct life cycle assessment work.

The assessment described here shows that the Directors' close involvement in the project supported knowledge growth and retention. Aligning with the findings of Chapter 3, and their own intentions, both Directors appear to have developed an embedded understanding of the environmental impacts of their products and an awareness of how to address these impacts. However the examination also identifies that the project did not transfer the practical knowledge needed to support ongoing eco-design development. Again this reflects the project's focus on developing an environmentally improved product whilst failing to consider its wider introductory role.

4.3.3 Objective 3: Identify any subsequent use of this knowledge within design activities.

As identified in Chapter 1 examining this interview objective is challenged by the difficulty of isolating the impact of the KTP project from other incidental drivers and identifying what has happened from what would have happened. What is generally observed is an improved understanding of the relative environmental weighting of the life cycle phases and an improved confidence in addressing salient product development aspects.

Prior to the start of the project, the Company had addressed their environmental impact through the introduction of a company-wide recycling scheme (Ref. Code 01). During the retrospective interviews the MD comments that;

“We are all a lot wiser on what matters and what doesn’t. You know it was interesting how the operation here is pretty good.” (Ref. Code 26)

Since the project’s completion the product development activities were found to align with the drivers described in Section 4.1.3, with significant work being done to reduce weights. In pursuit of weight reductions, the MD described the progressive weight reduction targets he had introduced across all product ranges.

“Now we don’t make a caravan over 1500kgs on a single axle. We did during the KTP project and now we don’t. I put a line in the sand and said we will never make another caravan that is over 1500kgs and hopefully before long I’ll say 1450 and then hopefully I’ll say 1400.” (Ref. Code 26)

The Technical Director discussed the challenges of meeting these targets.

“All the time now, we are focussing on weight, getting weight out of everything without losing strength, in order to improve the fuel economy.” (Ref. Code 27)

The MD describes the alignment between the environmental and other business drivers supporting this change.

“Weight reduction is the key bit that helps [reduce] CO₂ emissions and then helps the consumer to be more fuel efficient, both when they are towing and when they are not. So it is partly a market driven goal.” (Ref. Code 26)

What is clearly important to the success of this ongoing product improvement is that the eco-design drivers compliment other business drivers. Given that the Company

understand eco-design in purely product development terms and do not see eco-design as a driver in itself, the importance of this alignment is as expected.

Certainly weight is discussed most prominently during the retrospective interviews, with the MD referencing weight reduction 25 times; in contrast he makes only 5 references to aerodynamics and does not comment on the material reductions or rolling resistance projects at all. The references made to the improvement of aerodynamic performance, were in reference to a subsequent KTP project. Interestingly the aims of the next KTP project repeat many of the activities conducted in this project.

“We are looking to improve fuel efficiency, but purely working on aerodynamics and getting a greater understanding of what is important and what’s not in terms of shape and the importance of features such as aero windows, putting the curves on it or a slight horizontal on the back.” (Ref. Code 26)

The implication of this is that the Company’s aim for weight reduction during this KTP project reduced the engagement and embedded learning achieved in the other focus areas.

Despite a reduced focus by the Managing Director, the Technical Director’s revealed that there had been a change in the specification of the tyres since the project’s completion. Again this design change was supported by environmental improvements which aligned with other business drivers.

“Now we use the most fuel efficient and quietest tyre on the road. This cost us [more] money, but there’s been other benefits because it’s a well-known tyre brand. People recognise it because it’s always on TV.” (Ref. Code 27)

The Technical Director previous comments on the introduction of the curve on the rear was also supported by the assessment of publically available launch information which identified the inclusion of the rear curve on all subsequent caravan ranges.

The notable omission from the retrospective interviews is the ongoing development of the environmentally improved, low weight design concept. Despite having developed the concept through to prototype stage and having identified next steps for ongoing improvement, neither Director describes further development. The Managing Director did however imply the potential for future development.

“Yeah we still might do a mains only caravan. It would be for entry level to get the weight right down, like what you did. I think you were just a bit before your time.” (Ref. Code 26)

The KTP project aimed to develop an environmentally improved caravan that could be used as a basis for the caravan family for 2012 onwards. The project plan clearly assumed that the exemplification of an eco-design project and environmental product improvements would provide sufficient motivation to achieve this ongoing development. While there was still work to be done to complete the product concept, the lack of subsequent product development can be seen to challenge this assumption. That the MD still showed a continued interest in the concept, suggests that the project could have supported ongoing development by simply documenting and formally handing over the key next steps to someone within the Company’s product development team.

The retrospective review found that the Company had made several product design changes since the KTP projects completion (Ref. Code 28). While the completion of the project was not seen as being intrinsically linked to these developments, the Company’s ability to align environmental and business drivers was encouraging. The review also identified that the Company had not progressed the environmentally improved product prototype described in Section 3.6.2. Failure to integrate the development of this project, or at least formally hand over the next step to the Company’s product development teams, is seen as a clear contributor to this. It is important however, to note that these outcomes do not actually describe ongoing eco-design development. As predicted when discussing Retrospective Review Objective 2, the text grouped under this objective shows some of the results of the initial eco-design study still being used, but identifies no attempt to develop further eco-design knowledge, apply eco-design tools or measure the impact of subsequent design changes. Given that the KTP project did not transfer knowledge needed to build a vision for eco-design or the practical knowledge needed to undertake eco-design, this finding is somewhat inevitable.

4.3.4 Summarising the Findings of the Retrospective Review

The retrospective review found although the KTP project met the aims of the Company, developed their lifecycle knowledge and exemplified eco-design within their business context; it provided limited support or motivation for ongoing development. The reasons found for this poor support and development were:

- The project did not assess the Company's aims or drivers for eco-design development and did not align activities accordingly.
- As a result of the Company's nascent understanding of eco-design and the disproven assumption that the exemplification of environmental product improvements would sufficiently motivate ongoing development, the project pursued isolated product improvements and did not address the wider business context within which it was taking place.
- The product development focus prevented the wider business scope and potential of eco-design from being introduced, reducing expectations and limiting the development of aspirational goals.
- The project failed to adequately transfer the practical knowledge needed to support ongoing and independent eco-design.
- As a minimum the project did not formally document or hand over any of the key next steps identified for continued development. However, poor integration with the Company's product development team throughout the project can be seen to contribute to the lack of ongoing product design development.
- The project was not structured to address its introductory role.

The last of these points is perhaps the most critical. In Chapter 3 the Introductory Eco-design project was found to have two roles; to increase knowledge and understanding of eco-design, whilst promoting and supporting ongoing eco-design development. What has been shown in this retrospective review is that, from the outset, the KTP project did not sufficiently understand its introductory role and was not therefore designed to promote or support ongoing development.

4.4 A Second Retrospective Review

The KTP project applied a stand-alone, environmentally focussed product development project. As shown in the case study description, the application of this process successfully delivers environmentally improved outcomes (also supported by Ref. Code 24). What was found in the first retrospective review is that this achievement alone does little to promote ongoing development and can overlook some key activities needed to support the Company in doing so. The reason for this is that the project goals, objectives and structure of an environmentally focussed product development process, do not necessarily reflect those of the company. For a company in the nascent stage of eco-design development, the likelihood is reduced even further. As shown in this case study, this introduces a disconnection between the project and the company that reduces the project's ability to promote and support ongoing

development. What is proposed from this finding is that introductory projects should aim to reflect and work with existing company systems, rather than starting out from a position of best practice. Although this may reduce the environmental achievements made at the outset, it integrates learning into an organisation and allows eco-design to be experienced in non-disruptive way. Greater company and product change can then be worked towards as understanding and confidence increases. The difference between these two approaches can be understood by comparing Figure 42 and Figure 43.

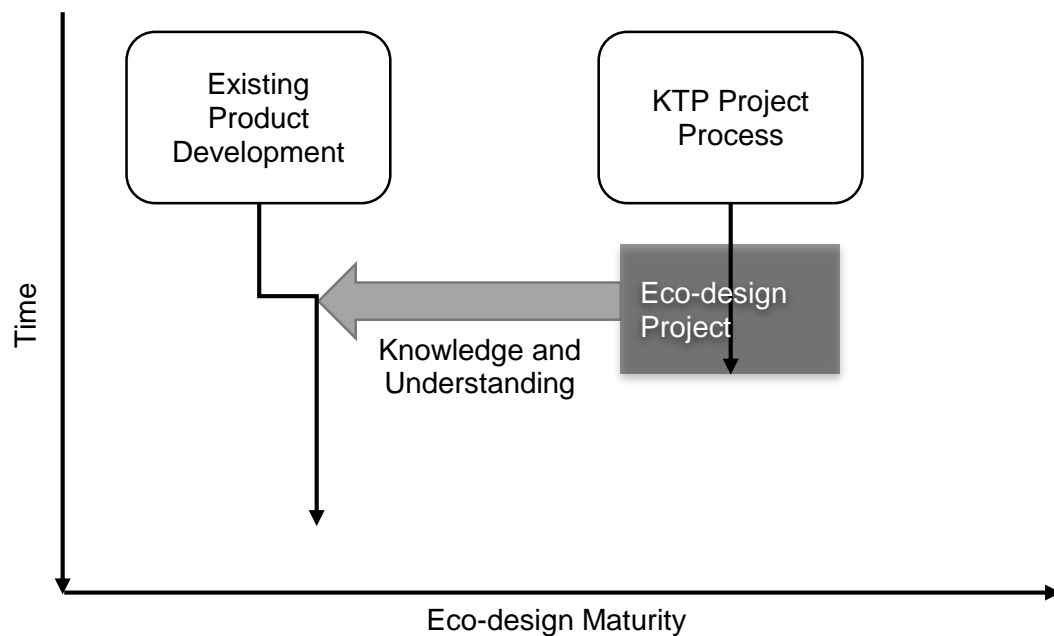


Figure 42: The Impact of the Environmentally Focussed Product Development Process Applied in the KTP Project

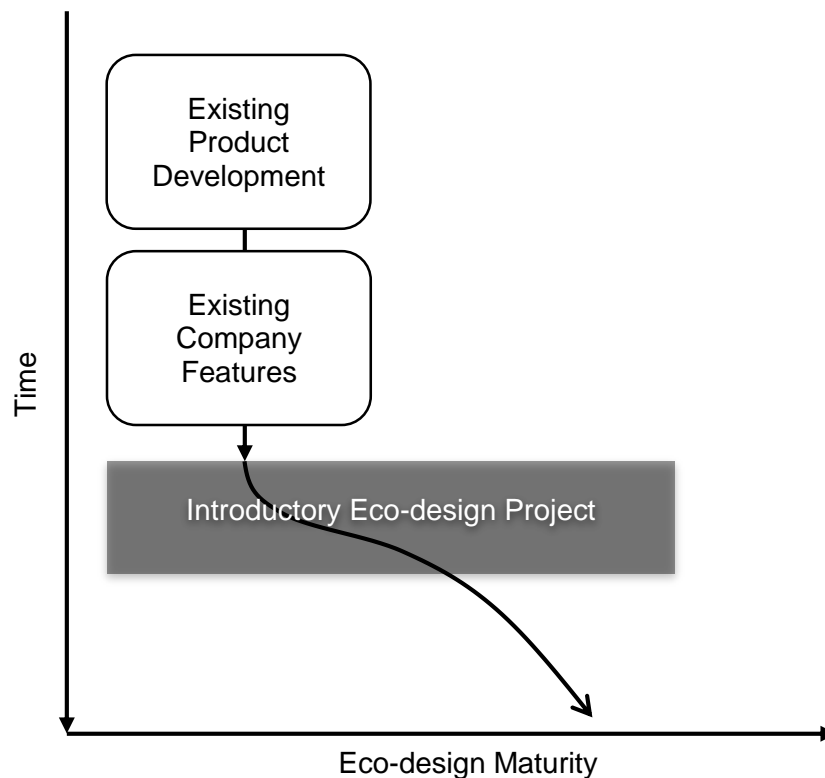


Figure 43: The Impact of the Proposed Introductory Eco-design Process using Existing Company Features to Integrate the Project and Promote and Support Ongoing Eco-design Development

During the research conducted so far, particular features of the business context, such as the Company's drivers for the project and the Company's relationship with their suppliers, have been found to impact the activities undertaken and the outcomes achieved ore significantly than others. As a result of this finding it was clear that in order to meet Objective 3 of this research and develop a process to support the development of introductory eco-design project as shown in Figure 43, the salient features of the wider business context needed to be identified.

These features were identified through a second retrospective review, this time focused on examining the existing company characteristics that had greatest impact on the project's activities and outcomes. All three research exercises undertaken in the first retrospective review were repeated the second time round.

The following sections provide a list of the identified company characteristics. Each section describes the evidence for the organisational characteristic identified and the impact it had on the work undertaken. Recommended improvements are then described, allowing learning outcomes to be defined.

4.4.1 Key Decision Makers in the Design Development Process

The company involved in the KTP project were a family run SME with an autocratic management structure. The MD, who had trained as an engineer and worked his way up through the design and engineering functions of the business, closely managed design development and production. The repeated use of the first person during the retrospective interviews reveals the concentrated nature of the decision making at the Company.

"If I don't sell that's my fault because I made the wrong product." (Ref. Code 26)

"When I spoke to the Purchasing Director and I said I want more bought from the UK." (Ref. Code 26)

The close involvement of this key decision maker was found to help the KTP project in embedding knowledge and supporting ongoing development. During the retrospective interviews the MD described how he was able to utilise the knowledge gained during externally supported projects, at opportune moments in the design development.

"Getting the weight down has knock on effects. It is about understands the impact on the hitch limit and the moment of inertia. The impact that aerodynamics have on this and how it changes to towing dynamics. A lot of what we have looked at with Bath University in the past is now sort of filtering in to make a better proposition going forward." (Ref. Code 26)

The evident challenge in this scenario is that if this decision maker is not motivated towards a particular change, there is no one internally to challenge their view.

In this small and autocratic organisation the identification and involvement of this individual was automatic, however it shows the importance of identifying the key decision makers during introductory activities and focussing motivating them towards ongoing development.

4.4.2 The Company's Product Development Cycle and Current Position

The Company had two product development cycles' that took place simultaneously. The most evident was the fast pace and continuous product alteration process that resulted in small design improvements. Alongside this rapid and continual product development cycle, a slower and more significant cycle was observed. Tracing the company's design history reveals a 5-10 year cadence for major technical design

changes, typically prompted by the availability of a new technology, material or manufacturing technique.

When the KTP project began the company had recently completed the development of their new caravan construction. The new construction resulted from a two year development project which saw the complete redesign of the caravan body. The first of these caravans was launched 3 months prior to the start of the KTP project (Ref. Code 02). As a result the Company were less willing to accept significant design changes, reducing the potential of eco-design. This was particularly evident in the aerodynamic project where changes to the body of the caravan were inherent, as shown in Table 24. In this instance, it may have been advisable to align the timing of the KTP project with the design development of the new construction. Aligning eco-design with other significant design changes increases opportunity and allows environmental information to be embedded within the design. The challenge of this approach is that it adds additional and unknown design criteria at a time when design resource is being fully utilised.

The assessment finds that a company's current position in their product development cycle impacts the potential for environmental development. As many organisation may not be able to select the opportune moment to commence eco-design, the introductory eco-design project should seek to understand and explicitly communicate the company's product development cycle and their current position on it. Planning activities around this current status will help inform the project scope, manage expectations and identify future opportunities for ongoing development.

4.4.3 The Design Development Process and Culture

The Company were, first and foremost, a manufacturing firm and as such their profitability was heavily dependent upon a constant output from the production line. As such the Company were centred on this activity and although they employed 250 members of staff, only 6 of these were employed in product design roles. The positive outcome of this, was that the team were adept and confident at delivering product development changes. During the retrospective interviews both the Technical Director and Managing Director displayed this confidence.

"It's been hard getting [the weight] down; I mean we've got it down now. My boost now, is for the [next model], and we're going to take another 100 kilograms out." (Ref. Code 27)

"It took us two and a half years to [change every layout to include a central gas bottle], because we had to do it progressively, but now all our gas bottles are in the middle." (Ref. Code 26)

Perhaps as a result of the Company's focussed delivery on product changes, a somewhat reactionary approach towards process development was observed. During the retrospective interview the Technical Directors described this reactionary development.

"Because no one was really managing the [design] office, the MD said to me, "could you take over, move to the [design] office and look at the drawing [process]"." (Ref. Code 27)

"They were still working on drawing boards, and I'd been working in [another company], they had been on CAD for ten years. So we introduced CAD for the next range." (Ref. Code 27)

A review of the meeting minutes also identified scepticism for the benefits of formal process more generally.

"MD noted that as all our timber is already FSC approved, we would need to establish if the time and investment needed to achieve accreditation would be worth it from a marketing perspective." (Ref. Code 05)

"The MD highlighted that he had no desire to seek ISO 9000 certification". (Ref. Code - 06)

"The MD highlighted that he has tried to avoid formalising improvement methods and that good communication between all parties leads to constant improvements." (Ref. Code 04)

The preference towards tacit rather than formal process is typical of a company this size (Desouza and Awazu, 2006). However identifying it as a cultural feature of the Company shows it as an important contributor to the product development focus defined in the KTP project plan. It also introduces questions as to whether the company would have accepted a project plan that focussed more heavily on the development of a business structure to support eco-design. When such structural and strategic changes were proposed to the MD during the retrospective interview, he seemed confused at first asking *"you mean how we operate?"*, before describing the role of the

KTP project as one of providing information to help guide product development (Ref. Code 26).

The impact of this characteristic is important because it reveals more detail about the role an introductory eco-design project must play. Clearly the Company's existing way of working will impact what they want from the project and the promotion of significant structural changes during the nascent stage of eco-design, is unlikely to be welcomed. Instead introductory activities should seek to integrate with the existing design development process and culture whilst introducing the changes needed to achieve more mature eco-design (see Table 2), and engendering motivation towards the changes.

4.4.4 Existing Product Design Drivers

Product design development within the caravan industry has been largely driven by three key factors since its inception; cost, functionality and weight. As previously shown the current focus on weight reduction greatly shaped the activities during and after the KTP project. However examination of all three design drivers offers further granularity that helps understand the impact of existing design drivers. The MDs discussion of design changes reveals these important aspects.

"You are getting to stage where you have to review what customers want in terms of specification, because we have come to a point where, we could probably take another 50 kilos out, I think, within the price constraints. I could make a carbon fibre caravan but no one can afford to buy it. Beyond that it's going to be de-specification and that depends on the consumer's willingness to accept it. 30 years ago the top of the range caravan had less than my entry level caravans today. But will the consumers be willing to sacrifice specification in the future?" (Ref. Code 26)

The quote reveals how the MD's is able to make intuitive judgements regarding the design trade-offs between traditional design drivers. This intuition is used to efficiently assess design concepts. In contrast the novelty of environmental design drivers requires the generation of a body of evidence to support design change, as seen in the aerodynamics project. As shown in this project the most successful eco-design developments during this nascent stage are those that can be easily translated into traditional design and business benefits.

What has been identified here is the importance of understanding the existing design drivers. In the nascent phase finding an eco-design opportunity that directly benefits a

traditional design driver or can be easily translated into traditional terms (often referred to as identifying win-wins) is promoted wherever possible. Again it is important that motivation towards more challenging aspects is also engendered during the project.

4.4.5 The Company Motivation and Business Drivers for Introductory Eco-design

For a company to undertake and fund an introductory eco-design project it must be driven or motivated to do so. As previously described, aligning introductory activities with the key driver(s) for the project, with help secure support and engagement within the company.

Equally many of the previous sections identify the importance of engendering motivation towards eco-design. This cannot be done without a clear understanding of the business drivers for eco-design within the Company's specific business context. The retrospective interviews reveal that even after the KTP project, the drivers for eco-design remained unclear.

"We have to become more eco because our market will expect it but it is dangerous to say you have a green product. You can talk about individual bits being quite green but to try and say that the whole thing is eco, is really hard and something to be very, very cautious about." (Ref. Code 26)

Given the inherent difficulty of integrating eco-design described above, these drivers become even more important for motivation. Failure to describe these drivers implies that the KTP project expected the Company to overcome these challenges without have a clear reason for doing so. This evidently contributes to the lack of ongoing eco-design development was observed in this case.

The assessment of this characteristic has found that the key driver(s) for the introductory eco-design project should be identified to help engender support and engagement during the project development. Equally all business drivers for eco-design should be identified to engender greater motivation for ongoing development.

4.4.6 The Product Value Chain and Maturity of Environmental Knowledge within it

As defined in the literature review, the product value chain includes all the activities involved in taking a product from conception to end use. The value chain is important because all actors influence the design or success of the product and therefore help to

define its environmental impact. All key actors and their roles along this value chain should therefore be identified. The environmental awareness of those within the value chain also impacts the resource required to tackle the subject, as shown in the KTP project description.

The upstream actors in this value chain predominantly consisted of suppliers, including single and multiple tier networks. The environmental knowledge of the suppliers was typically very low, due to the novelty of the subject within the caravan industry. The low level of knowledge and awareness was a significant challenge as it often meant that environmentally improved materials or product alternatives simply weren't available or feasible, as described by the Technical Director.

“The biggest problem was that you couldn’t get alternative materials at the right price. Everybody is still highly cost conscious all the time and they don’t make them in enough volume at the moment.” (Ref. Code 27)

Despite this novelty, the project plan focussed on the development of a complete environmental design within two years (Ref. Code 03). Not only does this set expectations very high by implying straightforwardness, it also prevents the project from focussing resource on the most significant challenges. Overcoming these challenges will be vital for the support of ongoing product development.

The downstream value chain actors are responsible for the market delivery of new products. The market launch of the electric only caravan was impacted by a poor understanding of these actors. When a new caravan is launched, the marketing team hold product awareness events with the dealer network. The dealers, who have direct and daily contact with the end users, act as a conduit for information between manufacturers and end users. The role of the dealers is so significant that they are viewed as the customers. This was revealed by the MD during the retrospective interviews, but crucially was not appreciated during the KTP project.

“Our customers are the dealers, and the dealers all get it. Because the dealers say the last thing they want to do in two years is take in a single axel part exchange that is 1600 kilos, because you need a whacking tow car to tow it.”

A successful launch of the electric only caravan concept was dependent upon the marketing department and dealer network understanding the benefits it offered. Failure to identify these important roles however, resulted in poor communication of the product’s novelty and benefits. The lack of general environmental awareness amongst

these actors further challenged this communication, as described by the Technical Director.

“The dealers have well established methods for selling caravans. They didn’t see [the environmental benefits of the electric only caravan]. We were trying to get that across to a dealer who is driving a Bentley, who doesn’t worry about the environment.” (Ref. Code 27)

As shown this not only impacted the launch of the product and provides further insights into the lack of ongoing development of this concept, but it also missed the opportunity to challenge current perspectives and increase awareness. Increased awareness by these parties was needed during the KTP project, but is equally important for the support of any future environmental efforts.

Evidently, understanding and documenting the value chain and the existing environmental knowledge within in, is important. As with most of the characteristics described here the documentation of these features would have enabled the project to be scoped to reflect the external environment. Identifying favourable features of the value chain, such as environmentally active suppliers, can greatly improve the efficiency of the work conducted. Conversely understanding the key challenges enables resource to be planned to tackle them.

4.4.7 Summarising the Findings of the Second Retrospective Review

The second retrospective review identified the six key company characteristics that most significantly impacted the KTP project’s ability to support and promote ongoing eco-design at the Company. In some instances the KTP project did address these characteristics (such as the involvement of the MD throughout) and the benefits that this offered have been described. In other instances (such as the identification of the drivers motivating the Company towards an introductory eco-design project) these characteristics were not addressed. Again the impact of this has been shown. What this promotes is the identification and communication of these characteristics prior to an introductory eco-design. The findings of the second retrospective review is that understanding these characteristics will enable the development of introductory eco-design projects that better reflect the company within which they take place. As a result the activities and outcomes of the project will be more integrated with the company and are more likely to support and promote ongoing eco-design development.

The literature review, case study description and retrospective reviews have provided a wealth of knowledge relating to the introduction of eco-design. The following chapter collates the learning outcomes from these three activities and combines them to develop an Introductory Eco-design Process and meet the third objective of this research.

5. Developing an Introductory Eco-design Process that Promotes and Supports Ongoing Development

The aim of this research is to investigate how introductory eco-design projects can promote and support ongoing eco-design development. The aim was identified through the completion of an introductory eco-design case study that had limited success in embedding eco-design following its completion. A review of the literature found that other authors had identified a typical pilot-project nature to many eco-design projects (Ammenberg and Sundin, 2005; Hernandez Pardo et al., 2011). A limited number of existing studies on the specific needs of the introductory context was also identified. To address these shortcomings and improve the impact of projects such as the case study described, the third research objective was identified.

Objective 3: Develop and review a process that supports introductory eco-design activities which promote and support ongoing development within design and manufacturing firms.

The following two chapters meet this objective by describing the development of an Introductory Eco-design Process designed to promote and support ongoing development, and reviewing its application within other industrial contexts.

5.1 Collating the Research Learning Outcomes

The Introductory Eco-design Process has been developed by combining the learning outcomes from each stage of the research; the literature review, case study description and both retrospective analyses. These learning outcomes have been collated into two primary groups and each group is described in detail in the subsequent sections. The first is an improved understanding of the company characteristics that impact the introduction of eco-design. These impacts form two sub-groups to this learning outcome; the nascent characteristics identified as common throughout companies in the nascent stage of eco-design development, and the company specific characteristics that impact the introduction of eco-design. The company specific characteristics describe a unique set of features that influence the introduction of eco-design. The second is an improved understanding of the project characteristics that support and challenge the introduction of eco-design. Through the summary of each learning outcome group a set of guidelines for the development of an Introductory Eco-design Process is iteratively developed. The outcome is an Introductory Eco-design Process that manages the nascent characteristics, addresses the unique combination

of company specific characteristics, whilst working through a series of activities that achieve project outcomes that promote and support ongoing eco-design development.

5.1.1 Improved Understanding of the Nascent Characteristics of a Company

The literature review identified some common characteristics of companies in the nascent stage of eco-design development. Reviewing the company described in the KTP project reveals a clear alignment with the characteristics, helping confirm their commonality. The examination of the KTP project and subsequent activities has however enabled a better understanding of the consequence of these characteristics on the introduction of eco-design. Table 26 describes the impact of these characteristics during the KTP project.

Nascent Characteristic	Consequence of Nascent Characteristic
Low eco-design knowledge and no experience of eco-design achievements	The Company's aims and goals for the first eco-design project were born from their nascent understanding of the topic. As a result the aims and expectations did not reflect their current capabilities or the capabilities of their value chain.
Low knowledge of eco-design tools and their application	Due to their lack of knowledge relating to the process of environmental assessment, the company tended to focus on the results of the eco-design tool but did not learn about the tool for future use.
Eco-design is viewed as a technical product development challenge.	The Company view changes to the organisational structure or processes as unnecessary for the achievement of a products environmental improvements.
Limited or ad hoc management and low resource commitment.	The management engagement and resource commitment reflected the extent to which the company could envisage the business drivers for each eco-design activities.
Driven by legislative compliance or competitive survival.	The primary driver for the company's initial interest in eco-design (in this case weight reduction) took priority and reduced the support and engagement shown for other development areas.
Low understanding of the business opportunities or risks posed by eco-design.	The Company were primarily interested in outcomes that supported traditional design drivers. This links with the management commitment of resource as described above.
Low motivation towards environmentally improved	The exemplification of an eco-design process and the achievement of product related improvements did not inherently promote ongoing eco-design

products.	development.
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Table 26: Improving the Understanding of the Characteristics of Companies in the Nascent Stage of Eco-design as a result of the Case Study and Analysis

The consequences of the nascent company characteristics are then used to improve upon the definition of the characteristic summarised from the literature. The improved characteristic is then used to identify the requirements of a company in the nascent stage of eco-design development, as shown in Table 27. These requirements must be addressed by the Introductory Eco-design Process and met by any eco-design introduction project.

Improved Description of the Nascent Characteristics	The Company Requirements when they are in the Nascent Stage of Eco-Design
Low eco-design knowledge and no experience of eco-design achievements, resulting in project aims and expectations that poorly reflect the existing capabilities of the company and the value chain.	<p>A clear understanding of the scope of eco-design and the inherent challenges it therefore poses.</p> <p>A clear understanding of the potential for eco-design within their organisation and the steps required to achieve it.</p> <p>Careful delivery of these aspects to ensure expectation management whilst maintaining optimism and motivation.</p>
Low knowledge of eco-design tools and a perception of complexity that encourages a focus on the results obtained rather than the tools themselves.	<p>A clear understanding of the links between the application of an eco-design tool and the utilisation of the information it provides.</p> <p>A clear understanding of how to use eco-design tools.</p> <p>The explicit identification of the personnel best placed to use the eco-design tools.</p>
Eco-design is viewed as a technical product development challenge that does not warrant changes to the company's existing structure or design process.	<p>A clear understanding of the scope of eco-design and the explicit identification of the benefits offered by this broader scope.</p> <p>The identification of this as a goal that the company can work towards rather than something that is required for the achievement of eco-design improvements.</p>
Poor visibility of link between eco-design and the company's traditional design drivers, resulting in limited management engagement and low resource commitment.	<p>Identification of eco-design activities that support the company's ability to address traditional design drivers, particularly economic drivers.</p> <p>A clear and detailed understanding of the resource commitment required to achieve these benefits.</p>
Activities are typically driven by a specific external driver, such as	A clear understanding of the primary driver for eco-design activities and the development of eco-

legislation or competitive survival. Addressing this driver will therefore be dominant early eco-design activities.	design activities that address this driver.
Low understanding of the business opportunities or risks posed by eco-design.	A clear understanding of the business opportunities and risks of eco-design, including the impacts of not addressing the key driver that initiated the company's interest in eco-design.
Low motivation towards environmentally improved products.	A clear vision and goal for eco-design, to help engender motivation for ongoing development. Sharing the vision, goal and business drivers with key decision makers to ensure key individuals are motivated towards environmental improvement.

Table 27: The Improved Understanding of Requirements of a Company in the Nascent Stage of Eco-design Development

The identification of the common needs of companies in the nascent stage of eco-design development has provided the following set of guidelines for the development of an Introductory Eco-design Process:

- Introduce the scope and potential of eco-design and contextualise the goal of the introductory activities within the achievement of this wider scope.
- Introduce the business opportunities and risks related to the Company's introduction of eco-design. The business drivers for eco-design should also be clearly defined.
- Engage company personnel in the process of eco-design ensuring the company understand the *process* undertaken during the introductory eco-design project, as well as the outcomes.
- Having introduced the business drivers for eco-design, select environmental improvement projects that enable the Company to address the key issue that initiated their eco-design interest. Project activities that have positive impacts on the company's ability to address traditional design drivers, particularly economic drivers, should also be prioritised in the first project.

5.1.2 Improved Understanding of The Company Specific Characteristics that Impact the Introduction of Eco-design

The second retrospective analysis applied an inductive approach to identify the company characteristics of most significance to the introductory eco-design context. Collectively the organisational characteristics identified provide a framework for understanding the existing organisational situation prior to the development and

completion of an introductory eco-design. As shown in the analysis, as exemplified in Figure 43, these company specific characteristic can be used to shape and form the introductory eco-design project to maximise its integration and impact within the organisation. Within the context of this research this collection of company specific characteristics has been termed the Company Characterisation Tool (CCT), shown in Figure 44.

The Company Characterisation Tool
<ul style="list-style-type: none"> - Key decision makers in the design development process - Design development process and culture - Product development cycle and current position - Existing product design drivers - Company motivation and business drivers for introductory eco-design - Product value chain and maturity of environmental knowledge within it.

Figure 44: The Characteristics found to Impact the Ongoing Development of Eco-design at the Company

Through its identification of key company characteristics impacting the introduction of eco-design, the CCT provides a streamlined process that enables the development of a realistic, relevant and integrated eco-design project plan.

The identification of the specific company characteristics that impact eco-design introduction provides the following guidelines for the development of an Introductory Eco-design Process:

- Describe each of the Company Specific Characteristics identified in the CCT.
- Use this information to develop Introductory Eco-design activities whose aims goals and activities reflect the Company Specific Characteristics.

5.1.3 Improved Understanding of the Project Features that Support and Challenge Ongoing Eco-design Development

The case study review and the retrospective analyses identified a wealth of project features that supported and challenged ongoing eco-design development. While the majority of these learning outcomes are covered by the development of nascent and company specific characteristics, some additional features were identified. These are grouped here and offer further guidance for the development of the Introductory Eco-design Process.

Features not contained within the previous summary exercises that were found to promote and support ongoing eco-design knowledge development and growth:

- The adoption of a lifecycle perspective that identified the most significant environmental aspects, improved design focus, increased the Company's perspective of their product and improved knowledge throughout the product life cycle.
- The development of a product design outcome. This aligned with the Company's product focussed way of working and supported their ability to envisage environmental improvements. It provided them with the experience of developing and producing an environmentally improved product and gave them insight into the opportunities and challenges involved.

Features of the KTP project were found to limit its ability to promote and support ongoing eco-design activity at the company:

- No explicit description of the key next steps for ongoing product development.
- No identification of the personnel required to conduct next steps or the formal hand over of this work.

This summary provides the following guidelines that can be added to those previously identified for the development of the Introductory Eco-design Process.

- Adopt a product lifecycle perspective to identify key impacts and encourage a broad view of environmental impacts. The broad view offers a range of development opportunities. The spectrum of potential development opportunities can then be aligned with the nascent and company specific characteristics, to select the most opportune.
- Promote engagement and motivation by ensuring that the project develops at least one tangible product or process improvement, over and above knowledge growth. The selection of a product or process improvement must reflect the Company's motivations for the project and their current ways of working.
- Define and communicate required next steps, identify the company personnel who will undertake this work. Conduct a formal hand over.

5.2 Developing The Introductory Eco-design Process

Collating these learning outcomes and following the guidelines has enabled the development of a seven step Introductory Eco-design Process, summarised in reference form in Appendix 5. Each of these steps is described below.

Step 1: Conduct a Project Kick Off and Eco-design Awareness Session

The Introductory Eco-design Process begins by conducting a knowledge development session that introduces the scope, breadth and depth of eco-design. The session should introduce lifecycle thinking and provide examples of improvements and benefits offered in other design and manufacturing organisations. During this session each subsequent stage of the Introductory Eco-design Process should be clearly described, including the generic aims and purpose of each. The overarching goal of the project and the contribution the project will make to the company's eco-design development should also be explicitly described. At this stage the awareness session will involve those assigned to the project prior to it commencing, however prior to the event an attempt should also be made to engage other key personnel, identified by managers.

During this session the Company are also encouraged to define their key aims and objectives for the project. Where misalignments between the aims and objectives of the Company and the Introductory Eco-design Process exist, these should be explicitly identified and discussed. Alterations to the process should be identified and agreed. At this stage the company also has the opportunity to ask questions, discuss and challenge any aspects of the Introductory Eco-design Process, to improve their nascent understanding of eco-design.

Step 2: Apply the Company Characterisation Tool

Collate information needed to define each aspect of the CCT through an analysis of relevant documentation, interviews company management and employees and observations made during time spent with the company. The CCT process can be continually improved during the first half of the Introductory Eco-design Process as new information becomes available and the eco-design practitioner's observations become more acute. The company characterisation produced by applying the CCT provides critical information for the development of a project plan that integrates and works with the company.

Step 3: Identify the Product Key Lifecycle Impacts (Environmental Hotspots)

Map out the key stages of the product life cycle and identify the most significant environmental impacts, also known as the environmental hotspots. As shown in this case study the lifecycle assessment process can be streamlined to enable better integration with the product development process. The degree of streamlining will depend on the product being developed, the level of interest from the company and the resource they are willing to commit at this early stage.

Step 4: Develop a Company-Specific Introductory Eco-design Project

The development of a Company-Specific Introductory Eco-design Project should take place over two sessions with the Company. Two sessions are suggested to reduce fatigue and allow those involved to contemplate the outcomes of the first before undertaking the second.

The first session, entitled 'Eco-design at [Company Name]', aims to collate the learning from Stages 1-3 to develop a goal and vision for long term eco-design at the company. This is done by building on the work done during Stage 1 and incorporating learning from stages 2 (particularly the business drivers for eco-design) and 3 (to help characterise what an environmentally improved product is), to establish a vision of where the Company *wants* to be. Closer analysis and discussion of the outcomes of Stages 2 and 3 are then used to fully describe where the Company is today. The final objective of this first session is to agree on a prioritised list of environmental activities that move the Company from where they are, to where they want to be.

The second session, entitled 'Introducing Eco-design to [Company Name]', aims to define the aims, objectives and scope of the Introductory Eco-design Project. This is done within the context of the long term plan developed in the first session, to ensure that it contributes to longer term development. The following guidelines should be followed when conducting this activity:

- The project goal(s) should be focussed on the achievement of tangible product or process improvements;
- The definition of easily achievable goal(s) is likely to produce more easily recognisable learning outcomes;
- The project aim(s) must address the primary driver that initiated the company's eco-design interest;
- The project aim(s) must have clear benefits to the company's traditional design drivers, whilst improving their understanding of eco-design drivers;
- The project activities must be achievable within the company's existing working structure, whilst identifying potential changes the company may wish to make to their structure in the future in support of eco-design;
- The project activities should be designed to incorporate low level engagement from key decision makers throughout the organisation.

Each stage of the company specific project plan is developed with the Company to ensure full understanding of the activities and the goals and motivations for their

inclusion. Subsequent updates to the Company-Specific Introductory Eco-design Project may take place iteratively during the first few months of the project, as the detail supporting Stages 2 and 3 develops.

Step 5: Conduct the Company-Specific Introductory Eco-design Project

Conduct the activities defined in the Company-Specific Introductory Eco-design Project engaging the personnel as defined in the plan. The number of people who are engaged in this first project will depend upon the availability of resource and support developed during steps 1-3. What is important is that key decision makers are engaged and detailed knowledge relating to both the process and outcomes of eco-design, are transferred to company personnel.

Step 6: Conduct a Project Review Session

The aim of this session is to identify the progress made, discuss the obstacles experienced and describe and agree next steps. This should describe how the project utilised environmental information and the methodologies and tools applied to obtain this information. The key next steps should be detailed and independently achievable by the company. An overall description of how the project has contributed to the company's longer term vision and how the outcomes can be utilised beyond the immediate next steps, should also be given during this session to promote ongoing development.

Step 7: Identify new Eco-design Champion(s) and Conduct a Formal Handover

By engaging with management it should be possible to identify the personnel who best placed to champion ongoing eco-design development. Conduct a formal hand over of the work undertaken and ensuring full details of each stage of the project and the next steps are given. Discuss and agree alterations based on the ideas of the new eco-design champion. The final step is designed to encourage engagement and ownership of the ongoing project.

The Introductory Eco-design Process is summarised in Figure 45.

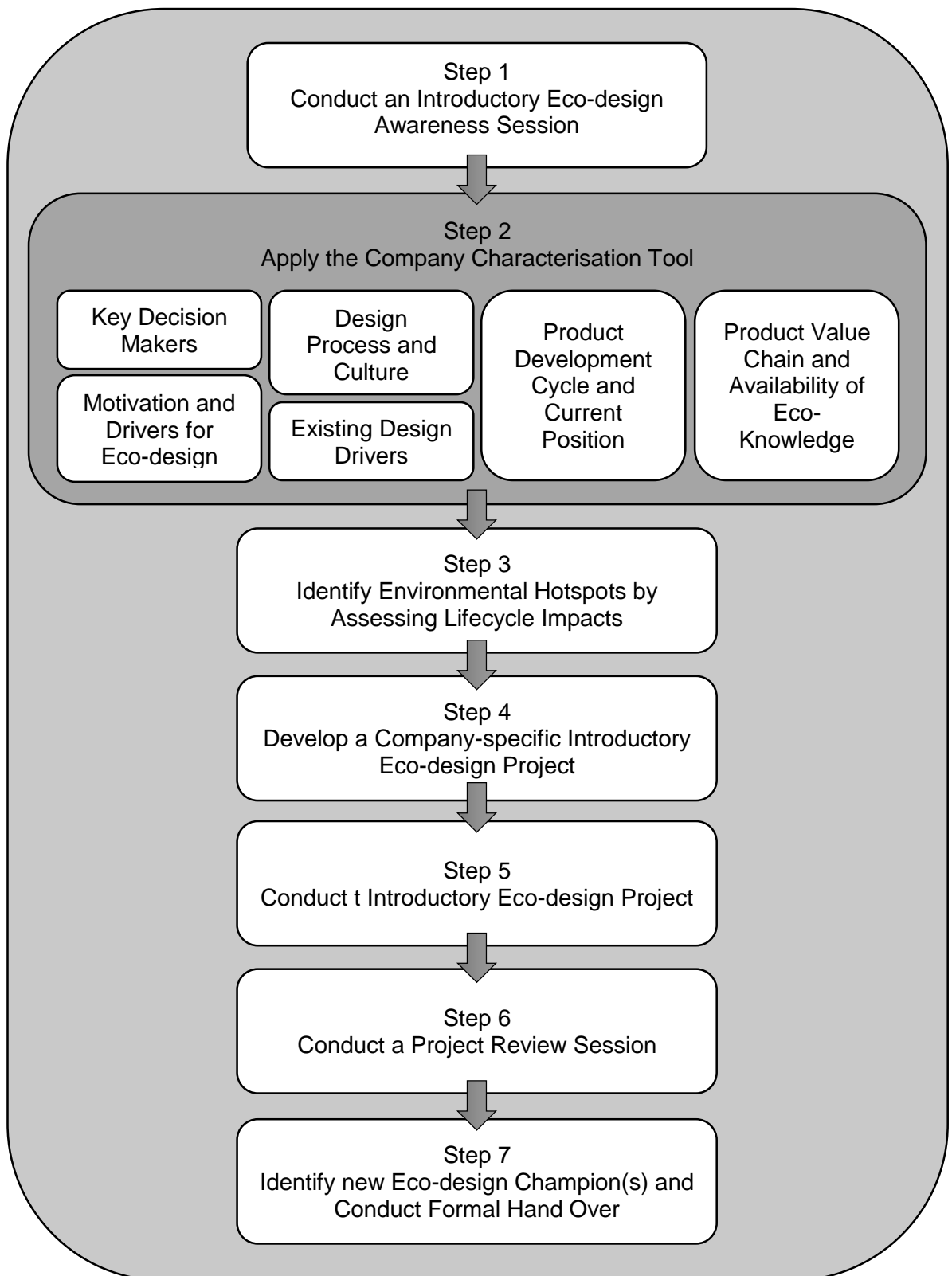


Figure 45: The Introductory Eco-design Process showing the Relationship of the CCT to the other Stages and the Information Flows

Section 2.3.4 found that previously existing eco-design methodologies were poorly matched to the characteristics of a company in the nascent stages of eco-design

development. To ensure that the Introductory Eco-design Process has addressed these limitations, Table 1Table 28 assess it against each of them.

Limitation of Eco-design Methodologies Reviewed in the Literature	How Limitation is Addressed in the Introductory Eco-design Process
1) Limited guidance for achieving key stages	The Introductory Eco-design Process provides a clear description of all stages required to work through the first project.
2) Commitment of significant resource	The resource required to complete the Introductory Eco-design Process is scalable and linked to the findings of the CCT. The resource commitment will therefore reflect, company commitment and current resource availability.
3) Require eco-design to be understood in strategic and operational terms	The Introductory Eco-design Process begins by introducing the wider strategic and operational aspects of eco-design. Step 4 then incorporates this learning into the eco-design project.

Table 28: Assessing the Introductory Eco-design Process against the limitations of the Methodologies Reviewed in the Literature

The assessment shown in Table 28 finds that by providing a clear step-by-step process and developing introductory eco-design activities that reflect the current business context, the Introductory Eco-design Process sufficiently addresses the limitations of previous methodologies.

6. Assessing the Applicability of the Research Findings in Other Industrial Contexts

The Introductory Eco-design Process was developed by collating the findings from an inductive assessment of a single detailed case study. The methodology introduces inherent limitations due to its development within a single industrial context. The following section examines the key limitation and the applicability of the tool to other industrial contexts. These exercises tentatively show that the Introductory Eco-design Process is applicable within other contexts.

The following section discusses key features of the methodology that may limit its use in other contexts. To examine the features in detail, a description of two research activities conducted after the development of the Introductory Eco-design Process, are then described. The first is a comparison of eco-design implementation within SME's vs multi-national organisations (Buckingham et al., 2014). The second is the utilisation of the Company Characterisation Tool within a second introductory eco-design project (Domingo et al., 2015). Both these research activities were conducted by the author with support, or in support, of other researchers. Where the work of other researchers is described, this is clearly identified as such.

6.1 Discussing the Impact of the Industrial Context on the Development of the Introductory Eco-design Process

Three primary features of the Introductory Eco-design are seen to have been shaped by the specific context of the KTP project and could thereby limit its application more broadly: the management of the process by an external practitioner with eco-design experience; the size of the Company involved; and the Company Characteristics included in the CCT.

6.1.1 External Management of the Introductory Eco-design Process

The KTP project was managed by the author of this dissertation during a fixed term with the Company. The author had prior knowledge of eco-design and was supported by further academic support and knowledge. As a result the Introductory Eco-design process has been developed with a similar structure in mind. This is not viewed as a significant limitations in others contexts, due to regularity with which companies in the nascent stage obtain support from external parties to address their limited knowledge (Hernandez Pardo et al., 2011; Prendeville et al., 2011; White et al., 2008). It is also noted that steps 4-7 can be conducted by a company independently once the

information obtained in steps 1-3 is available. For other applications, there is no indication why all the stages could not be done in-house by a company, through systematic deployment of this process and intensive training of some key-staff. This potential flexibility would also allow the level and duration of external support to be tailored to meet existing resource availability.

6.1.2 The Scale of the Organisation

The size of the Company involved in the KTP project can be seen to impact the relevance of certain aspects of the Company Characterisation Tool.

Many authors make reference to specific challenges facing the introduction of eco-design within SMEs (Ammenberg and Sundin, 2005; Fernández-Viñé et al., 2010; Hillary, 2004; Prendeville et al., 2011; Reyes and Rohmer, 2009). What is largely agreed is that internal company characteristics tend to have a greater influence over successful eco-design introduction in SMEs. What this may mean is that the characteristics identified in the CCT may have less relevance in larger organisations.

To explore this possible limitation, the experience of conducting eco-design within an SME, was compared with that of a larger organisations. This study was reported in a paper (Buckingham et al., 2014) that compared the KTP project and with the application of the Eco-M2 process within a larger organisation (Pigosso, 2012). The content relating to the multinational organisation was contributed to the research by Pigosso.

Comparing the Opportunities and Barriers to Eco-design within an SME and a Multinational Organisation	
<u>The Opportunities</u>	
<u>SME</u>	<u>Multinational Organisation</u>
<ul style="list-style-type: none"> - Small number of decision makers simplified knowledge transfer process - Small number of decision makers made change fast and dynamic - Trial and error approach to product development - if it worked the company were happy to incorporate it. 	<ul style="list-style-type: none"> - Sustainability strategy drives a long term planning for eco-design implementation in the organisation. - Eco-design implementation is seen as a comprehensive long-term program, with several different complementary projects running in parallel. - Possibility to obtain specialised support from different internal stakeholders, which can enhance

	eco-design implementation. <ul style="list-style-type: none"> - Changes in the formalised processes and procedures usually lead to change in the behaviour of employees.
The Barriers	
<u>SME</u>	<u>Multinational</u>
<ul style="list-style-type: none"> - Focus on traditional value adding activities with limited strategic planning, resulting in a misplaced focus for eco-design activities. - Small number of decision makers, made individuals very powerful (if MD did not agree, it did not happen) - Limited environmental knowledge throughout the business and supply chain and low influence over most suppliers - Limited data or knowledge management, making environmental data difficult to incorporate within decision making. - Trial-and-error approach relied on currently viable options with no long term storage of 'pipeline' technologies or materials. - Low availability of design and development resource demanded a very clear business case for environmental improvements. 	<ul style="list-style-type: none"> - Large numbers of decision makers, making it difficult and time consuming to reach a consensus. - Highly formalised process, making it difficult to introduce new activities related to eco-design and slowing the pace of product and procedural change. - Size of the organisation makes it difficult to obtain a clear view of the current processes and responsibilities. - Size of the organisation demands formal knowledge development and dissemination. Training is a huge and time consuming task. - Limited knowledge of eco-design and its benefits, resulting in low budgets being assigned to its implementation and demanding a very clear business case.

Table 29: The Opportunities and Barriers to Eco-design within a Multinational Organisation (Buckingham et al., 2014)

Table 29 shows how the SME's hierarchical and flexible design process helped ensure that key decision makers were informed and design decisions were taken quickly. In contrast the high level of formalisation present in the larger organisation posed significant challenges due to the difficulty of changing working practices. The potential benefits offered by the smaller size of SME's are also discussed by Short et al (2012), who proposed that "it might be easier to implement DfS/E in small companies where a Senior Manager is perhaps more autocratic and more easily able to implement changes", and that "with a less structured design process...the "system", such as it is, could be more flexible to incorporate new methods." (Short et al., 2012)

The largely informal and highly flexible approach promoted by the Introductory Eco-design is clearly a consequence of the more flexible organisational structure within which the tool was developed. While this may be favoured by smaller organisations, it may not align with the more structured and formal working practices present in larger organisations and may fail to gain traction as a result. As the aim of the process is to ensure the development of an introductory eco-design process that easily integrates and aligns with existing working practices, this contradiction is likely to inhibit the use of this tool in larger organisations.

The following section describes the application of the Company Characterisation Tool (CCT) within the development of an introductory eco-design project at a medium sized organisation. This finds the tool to be useful and applicable within this organisation. The descriptions included in this section, however reveal that further research would be needed to understand if there is a size limit at which the methodology's relevance diminishes.

6.2 Applying the Company Characterisation Process within the Development of a Second Introductory Eco-design Project

Following the completion of the KTP project the author began working on the introduction of eco-design within other organisations as part of the European FP7 funded Green Engineering and Design project (G.EN.ESI). Within the context of this project the Company Characterisation Tool was used to develop an Introductory Eco-design project plan, within a medium sized design and manufacturing firm (Domingo et al., 2015). Although the company was medium in size, it was part of a larger group of companies who developed kitchen solutions. Again the application of the tool was conducted during an academically-supported project and the company had no prior experience of eco-design development. The data collection and application of the Company Characterisation Tool was completed by the author of this dissertation. The development of the Company Specific Introductory Eco-design Project and assessment of the tool was conducted by Domingo.

Despite the larger size of the organisation, the information gathering required to apply the CCT was found to be both achievable and resource efficient. The key activity involved in this data collection was a two-day technical immersion visit by the author. During this visit, the product development process was discussed in detail, interviews (develop to inform the CCT process) were conducted with members of the design and development team and observations were made of the design development teams. The

discussion and observations were supported by product development process documentation, which, given the larger size of the organisation, was readily available.

The outcome of this work found that the CCT was achievable and relevant to the development of meaningful introductory eco-design activities. Domingo et al. (2015) describe the four key benefits from the application of the CCT:

- 1) The aligning of eco-design activities with key eco-design and traditional design drivers at the company – the company had an impending tradeshow at which they were keen to promote their eco-design activities. The identification of this driver allowed the academic team to utilise this aim to develop targeted eco-design training within the company and promote the development of eco-design ideas to support this aim.
- 2) Developing a contained and focussed eco-design pilot project – this resulted in the modification of the type of component used within their core product (i.e. a small change made to a large number of products). The experience provided the company with a tangible knowledge of eco-design and a relatively easy introduction to eco-design achievements.
- 3) Developing the long term vision for eco-design through the contextualisation of introductory activities – by establishing an understanding of the current position of the business, a clear view of the long term goals was obtained. As a result long-term eco-design plans were defined to embed eco-design into a continuous improvement process.
- 4) The contextualisation of training material improved company appeal – as a result of the characteristics identified in the CCT, training content was aligned to the product and development processes at the company. As a result of this relevance the appeal of these training sessions extended to employees not directly involved in the project. This helped widen the scope of eco-design learning.

The work of Domingo et al, showed that the CCT was effective when applied in a medium sized organisation.

More generally the research described in this section finds that the Introductory Eco-design Process is applicable within other industrial context and therefore provides learning for other eco-design experts, undertaking introductory eco-design projects. Further research is needed to test these findings more broadly, particularly within larger organisations, however these initial results are promising.

7. Conclusions, Contributions to Knowledge and Further Work

The research project presented here set out with the following aim:

“Investigate how introductory eco-design projects can promote and support ongoing eco-design development within design and manufacturing companies.”

To meet this aim, the dissertation describes a series of research activities that culminate in the developed an Introductory Eco-design Process. The Introductory Eco-design Process has been developed to support those conducting the first eco-design project during a company’s nascent stage of development. The Process was developed through an inductive analysis of existing literature and an introductory eco-design case study. Adopting an inductive approach enabled the specific requirements of the introductory phase to be identified from the experience of the author and other authors, from the reviewed literature. As a result the Process has been specifically designed to address the needs of a company in the nascent stage of eco-design development, whilst promoting and supporting ongoing eco-design development.

To exemplify how the research met this aim, the following section provides a summary of the dissertation and research conducted. The subsequent section then shows how the project has met each of the three research objectives. The final section of this dissertation defines its contribution to knowledge and identifies areas of further work that will support the maturation of the Introductory Eco-design Process.

7.1 The Work Undertaken to Meet the Research Aim

To meet this research aim the dissertation describes five key stages to this research.

- 1) Chapter 2 describes the findings of a literature review that defines eco-design within the context of this research, examines companies in the nascent stages of eco-design and summarises the existing recommendations and methodologies aimed at moving past this introductory phase. The literature review finds that existing recommendations and methodologies are poorly matched to the characteristics of a company in the nascent stages of eco-design development.
- 2) Chapter 3 provides a case study of an introductory eco-design conducted in a company with no prior knowledge or experience of the topic. Through an examination of the project aims, objectives, activities and outcomes, the case

study finds that although the environmentally focussed product development process achieved significant design results, it appears to have done little to promote or support ongoing eco-design at the Company. As a result of the case study description, the role of the introductory eco-design project is defined.

- 3) Chapter 4 details a retrospective review of the case study conducted to examine its apparent failure to promote or support ongoing eco-design development. The Chapter collates the findings from two retrospective interviews held with the companies Managing and Technical Directors, an analysis of real time documentation from the project and a review of subsequent product launches by the Company. The retrospective review finds that the project poorly promoted or supported ongoing eco-design development due to the disconnected approach it adopted. The outcome of this Chapter is the identification of a set of key company characteristics that shape the way a company interacts with the first eco-design project.
- 4) Chapter 5 collates and summarises from the literature review, case study description and retrospective review. The learning outcomes from each are then incorporated within the development of an Introductory Eco-design Process. The 7 step process supports the development of project aims, activities and outcomes that increase knowledge and understanding whilst promoting and supporting ongoing eco-design development.
- 5) Addressing the limitations of applying an inductive approach to the assessment of a single case study, the final stage of this research assess the application of the Introductory Eco-design Process in other industrial contexts. The research provides an example of the tools successful application within a medium sized organisation, but finds that it may be less relevant in large companies where structured and formal working practises dominate.

7.2 Meeting the Objectives of the Research Project

The research project also set out to achieve three objectives. The achievement of these objectives is described below:

Objective1: Describe the introductory eco-design context in detail and identify the key opportunities and challenges presented by it.

The research described here, met this objective in two key ways. First the detailed description of the case study provides empirical evidence of the opportunities and practical barriers associated with the introduction of eco-design. Secondly findings of the literature review and retrospective analyses were used to identify characteristics

that describe companies in the nascent stage of eco-design. From this definition, the requirements of companies in this stage were also identified.

Objective 2: Taking a longitudinal perspective, assess the impact of introductory eco-design activities in the longer term and their ability to motivate and support ongoing eco-design activity.

Two retrospective analyses are conducted within this research to examine the impact of introductory eco-design activities in the long term. The outcome of these reviews is the finding that introductory eco-design activities must explicitly set out to support and promote eco-design development. To do this an integrated approach is promoted through the identification of key company characteristics that effect introductory eco-design efforts.

Objective 3: Develop and review a tool for the development of introductory eco-design activities aimed at promoting and supporting ongoing development within design and manufacturing firms.

The research meets this objective through the development of the Introductory Eco-design Process. The inductive methodology adopted in this research project ensures that the Process is a product of the detailed of introductory eco-design case study. To address the limitations introduced by the use of a single case study in this inductive development, the research concludes with an assessment of the application of the Process in other organisational contexts.

7.3 Contributions to Knowledge and Recommendations for Further Work

The literature reviewed identified a gap in existing knowledge leading to poor support for the introduction of eco-design in company in the nascent stage of eco-design development. To address this gap this dissertations has provided the following contributions to knowledge:

- A set of common characteristics for companies in the nascent stage of eco-design, as described in Table 27.
- A list of company requirements that must be met when undertaking eco-design for the first time.
- A framework for understanding a company prior to conducting an introductory eco-design process, through the description of salient company characteristics.

- An Introductory Eco-design Process that supports the development of projects that increase environmental knowledge and understanding, whilst promoting and supporting ongoing eco-design development.

To advance this work further the following list of activities has been identified:

- Utilise the Introductory Eco-design Process within more design and manufacturing firms of varying size. The application of this process within more organisational context for three primary reasons. Firstly the characteristics within the CCT must be refined through an assessment of their relevance in other organisational contexts, and the utilisation of the information it provides. Secondly the seven step process must be refined through an assessment of the successes and challenges presented by its application. Finally the ability of the overall Process structure and content must be refined through an assessment of its achievements in supporting and promoting ongoing eco-design development.
- As the research identified the importance of motivating individuals towards eco-design development, the author also recognises the potential improvement offered by an examination of the psychology of motivation. The learning outcomes from this exercise could significantly change and improve the activities included in the seven step Process.
- The research also identified the importance of understanding the business drivers for eco-design. As such, further work examining the economic impact of eco-design activities and borrowing learning from the increasing body of work that examines the application of life cycle costing, alongside lifecycle assessment, is seen as important (Carlsson Reich, 2005; Gluch and Baumann, 2004; Heijungs et al., 2013; Hoogmartens et al., 2014; LUO and WEI, 2014; Senthil et al., 2003). The learning outcomes from this exercise would further support the Process' ability to integrate and engage with companies and increase its ability to promote and support ongoing eco-design development by appealing to their economic bottom line.

8. Appendices

8.1 Appendix 1: Customer Questionnaire Completed to Inform LCA In-use Phase

1. Are you?

- ☐ Male
- ☐ Female

2. What age are you?

- ☐ Under 35
- ☐ Between 36-55
- ☐ Between 55-75
- ☐ Over 75

3. What is the manufacturer, make and model of your current caravan?

4. In what year was your caravan manufactured?

5. How many berths does your caravan have?

6. What is the manufacturer, make and model of your current tow vehicle?

7. What is the kerb weight of your tow vehicle?

- ☐ Less than 1300kg
- ☐ 1301kg - 1400kg
- ☐ 1401kg - 1500kg
- ☐ 1501kg - 1600kg

☐ Over 1600kg

8. Does your vehicle run on diesel or petrol?

☐ Diesel

☐ Petrol

9. What is the fuel consumption of your tow vehicle when towing and when driving solo (MPG)?

10. Do you tow your caravan regularly or is it sited in a single location for extended periods?

☐ Tow

☐ Sited

11. How many weekend breaks did you take in your caravan in 2009?

0 1 2 3 4 5 6 7 8 9 10+

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

12. For each of the four holiday types identified, please state how many you took in your caravan in 2009:

0 1 2 3 4 Over 4

Holiday of 1-2 weeks within the UK ☐ ☐ ☐ ☐ ☐ ☐

Holiday of 1-2 weeks outside the UK ☐ ☐ ☐ ☐ ☐ ☐

Holiday over 2 weeks with the UK ☐ ☐ ☐ ☐ ☐ ☐

Holiday over 2 weeks outside the UK ☐ ☐ ☐ ☐ ☐ ☐

13. Please state the total distance you towed your caravan during 2009 (in miles):

14. How often do you go on caravan holidays with the following groups?

	Always	Often	Sometimes	Never
On your own	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
With your partner	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
With your immediate family	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
With your extended family	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
With your friends	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

15. When you are on your caravan holiday, where do you spend most of your time?

	On-site	Off-site
During the day	<input type="radio"/>	<input type="radio"/>
During the evening	<input type="radio"/>	<input type="radio"/>

16. Which of these activities do you commonly take part in when you are on a caravan holiday?

- ☐ Walking
- ☐ Swimming
- ☐ Surfing

- ☐ Golf
- ☐ Visiting local theme park / zoo / activity centre
- ☐ Reading
- ☐ Watching TV / DVDs
- ☐ Eating at local restaurants
- ☐ On-site entertainment / activities
- ☐ Cycling
- ☐ Other

17. Which power supply do you use most regularly when you are on a caravan holiday?

- ☐ Mains hook-up (230v)
- ☐ Battery (12v)

18. Thinking back to your last caravan holiday, how often did you use the following appliances within your caravan?

	Every day	Every few days	Occasionally	Never
Grill / Hob / Cooker	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Room heater	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Refrigerator	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Water heater	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
BBQ point	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

19. Thinking back to your last caravan holiday how regularly did you use the following facilities in your caravan?

	Every day	Every few days	Occasionally	Never
Shower	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Toilet	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Oven	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Grill	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Hob	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Microwave	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Refrigerator	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Room heater	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Television	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
CD / Radio player	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

20. Rate the importance of the following features when purchasing a caravan:

	Very important	Quite important	Not important
Price	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Layout	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Interior decor	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Specification	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Weight	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Retailer	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
External appearance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Brand	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

21. Have you purchased any of the following items of equipment for your caravan?

- ☐ Air conditioning
- ☐ Motor mover
- ☐ Solar panels
- ☐ Awning heater
- ☐ LED lights
- ☐ Satellite television aerial

22. Is there anything that you particularly like or dislike about your current caravan and why?

23. If any, what modifications have you made to your caravan and why?

8.2 Appendix 2: Fuel Consumption Test Report: Square vs Curved Rear Upper Edge

8.1.1 Goal

The aim of the test was to calculate the fuel saving (if any) which results from the curved rear upper edge, compared with the conventional square shaped profile.

8.1.2 Test Equipment

The test uses two caravans, one had a curved upper rear edge ("the curved caravan"), and the other had a square upper rear edge ("the square caravan").

The curved caravan is a four berth caravan with a body shell length of 5298mm. The total weight of the caravan is 1072kg and this is distributed accordingly:

Near Side (Side with Door) = 480kg

Off Side = 519kg

Nose = 73kg

The square is a four berth caravan with a body shell length of 5276mm. The total weight of the caravan is 1102.5kg and this is distributed accordingly:

Near Side = 481.5kg

Off Side = 532kg

Nose = 88.9kg

In order to ensure that the two caravans had the same weight the difference between these figures was calculated and weight was added to the curved edge caravan in the following proportions:

Near Side = 1.5kg

Off Side = 13kg

Nose = 15.9kg

An estate car was used to tow both caravans, as it offered cruise control and an on board speed and fuel consumption monitor. The same car was used in all tests.

8.1.3 Methodology

The car and caravan was driven at a fixed speed of 60MPH, as set by the on-board cruise control. The test route was a distance of 15 miles and was chosen as it is relatively level throughout.

In order to minimise the effects of head or tail winds, the test was conducted in both directions. Separate results were recorded for the outbound and inbound legs of the journey. The test was repeated twice for each caravan in order to help minimise the impact of anomalies, such as acceleration, deceleration, and interference from other traffic and weather effects.

The car and caravan was driven to a common start point at a distance of 10 miles from the factory. This enable the car engine to warm up before measurement began. At the beginning of each test run the car and caravan were brought to a halt, meaning that all fuel consumption results include acceleration from 0-60MPH. Once the car and caravan reached 60 MPH, the cruise control was set at this speed. This speed was then maintained for the full 15 miles to a common end point. At this point the average miles-per-gallon reading was taken from the on board computer.

8.1.4 Results

In total testing was completed on four different days, with some variability in the tests completed and conditions. The results and any variability in the testing are summarised in the Table 30. Variability included weather conditions, as well as the need to brake for other vehicles.

Average Results - Fuel Consumption (MPG)				
	Square Caravan	Curved Caravan	Improvement (%)	Comments
Test One	N/A	33.6	N/A	Due to time taken setting up the test, unable to test square back on Day 1.
		33.6	N/A	
Test Two	31.1	32.6	4.6	Wet conditions, deceleration and acceleration by 5 MPG during outgoing journey.
	31.1	34.4	9.6	
Test Three	29.2	34.1	14.4	Deceleration and acceleration by 3MPG during outgoing journey.

	31.3	30.0	-3.3	
Test Four (no cruise control)	N/A	33.2	12.05	
		30.7	-1.95	
Average	30.67	32.78	5.9%	

Table 30: Fuel Consumption Comparison between the Square Back and Curved Back Caravan Designs

Test Four was conducted to help understand the impact that cruise control was having on the results. The car was held manually at 60MPH throughout the test. These figures show very little difference compare to those conducted with cruise control. The percentage improvement figures shown in Table 30 result from a comparison with the Square Caravan figures obtained in Test 3. This was deemed to be comparable as the Square Caravan test was conducted within the same three hour period, on the same day.

8.1.4 Review of Methodology and Conclusion

The methodology used for this testing was susceptible to a high level of variance. Weather variations, such as wind and rain, are likely to impact the results by increasing air pressure on the front of the car and reducing rolling resistance. Differing interactions with other vehicles and the turbulent air that they generate was another uncontrollable factor in the testing. Despite these difficulties the results found that the curved rear offered an average fuel saving of approximately 5%.

The next stage was to understand if this saving translated into a marketable cost saving. Taking an average annual towing distance of 2000 miles (as used in the medium use phase model), the 2.11MPG increase achieved by the introduction of the curve, saved around 4 gallons of diesel per year, amounting to a cost saving of between £21 and £25 per year, dependent upon diesel costs. These low cost savings were not deemed to be high enough for marketing figures and the marketing department decided instead to use a 5% fuel saving figure in marketing material.

8.3 Appendix 3: Semi Structure Interviews Developed for the Longitudinal Assessment

Introduction

(Welcome and thank you for agreeing to take part in the interview.

Ask permission to record the interview and assure the interviewee that all information will remain anonymous.)

Questions

Non-challenging to ease interviewee into the process

- So how long have you been employed at the Company?
- You are now the.....but did you have any job roles prior to this? Can you tell me your progression through the company and the various roles you have had in the business?

(Explain research project and how this interview contributes to it. Explain that the interview is about the KTP project that I was involved in.)

To understand their view of the project without making them feel examined or tested

- Can you tell me about how the KTP project came about?
 - Where did the initial idea come from – university or company?
 - Where did the environmental design focus come from?
 - How did the project plan transpire?
- What were your expectations, aims and goals for the KTP project?
- How did this KTP project fit into your wider business objectives?
 - Please can you explain a bit about the wider context that led to you conducting a KTP project?
- Please can you talk about the extent to which your expectations, aims and goals were met by this project?
 - **Expectations were not met** – Can you discuss how and why you feel that was? What changes would you have made to ensure that the project was better able to meet your expectations? (Probe this topic to ensure that the company's key recommendations for improvement are identified)

- **Expectations met** - Can you expand on this and give examples of how?
Please can you explain why you feel that the project was able to meet these expectations? (Again probe to ensure key success factors are identified)
- **Expectations exceed** - Can you discuss how and explain why you feel that the project was able to exceed expectations? (Probe this topic to ensure that the company's key success factors are identified)
- This particular project resulted in the development of the electric only caravan. What happened to this product after the project's completion?
 - What did the company learn from the production of this product?
 - To what extent has this experience helped shape future strategy at the company?

To understand what long term impacts the project had on the company

- To what extent do you feel that the KTP project transferred knowledge to the company?
- What were the key learning outcomes for your company?
 - Explain the definition of 'environmental initiative' vs 'eco-design'
- The KTP project resulted in the development of the electric only caravan. What is your view of this project outcome?
 - What did the company learn from the production of this product?
 - To what extent has this experience helped shape future strategy at the company?
- How do you view environmental improvement initiatives and their relevance to your business today?
 - **If positive** – To what extent did the previous KTP project influence your future plans for environmental initiatives?
 - Do you have further environmental initiatives planned? (expand on this to ensure that full details are given – strategy for this development, how this development will be conducted, their goals, whether it will be an externally supported projects or internal efforts)
 - **If negative** – please can you explain why you have come to this opinion? (ensure that there interviewee has given an in-depth description as to why)

- To what extent did the previous KTP project contribute to this opinion?
- Referring to eco-design specifically how do you view this and its relevance to your business today?
 - **If positive** – To what extent did the previous KTP project influence your future eco-design plans?
 - Do you have any plans for future eco-design activities within your business? (expand on this to ensure that full details are given – strategy for this development, how this development will be conducted, their goals, whether it will be an externally supported projects or internal efforts)
 - **If negative** – please can you explain why you have come to this opinion? (ensure that there interviewee has given an in-depth description as to why)
 - To what extent did the previous KTP project contribute to this opinion?

Conversational section to encourage further comments from the interviewee.

- Do you have any further comments that you would like to make about the KTP project, your companies environmental initiative, eco-design or collaboration with external teams?

Thank interviewee and conclude interview.

8.4 Appendix 4: List of References Used for Retrospective Reviews

Table 31 provides a full list of the references review to support the retrospective analyses described in Chapter 4. In some instances descriptions are given rather than the full reference to maintain the participating company's anonymity.

Reference Code	Document Title	Date	Source
01	Environmental Awareness	01/08/08	Company website describing their actions to reduce environment impacts
02	New Caravan Body Construction Website	06/01/09	Company Marketing Webpage to Support Launch of New Caravan Body Construction
03	KTP Grant Application and Proposal Form	01/03/09	Grant Application and Original Project Plan completed by Company and KTP Office at the University of Bath
04	Monthly Meeting 1 - Minutes	01/03/10	Primary Source – Author's Minutes
05	Monthly Meeting 2 – Minutes	12/03/10	Primary Source – Author's Minutes
06	Monthly Meeting 3 – Minutes	10/05/10	Primary Source – Author's Minutes
07	Research Report	24/05/10	Primary Source – Report written by Author and shared with KTP Team
08	Manufacturing Caravans	25/05/10	Primary Source – Report written by Author and shared with KTP Team
09	The Life Cycle Assessment of the Mid-Range Caravan	24/06/10	Primary Source – Report written by Author and shared with KTP Team
10	Monthly Meeting 4 - Minutes	28/06/10	Primary Source – Author's Minutes
11	Monthly Meeting 5 - Minutes	23/08/10	Primary Source – Author's Minutes
12	Monthly Meeting 6 - Minutes	05/10/10	Primary Source – Author's Minutes
13	Monthly Meeting 7 - Minutes	15/11/10	Primary Source – Author's Minutes
14	Customer Questionnaire - A Summary	07/12/10	Primary Source - Report Written by Author shared with KTP Team and Company's Marketing and Sales Teams
15	Technical Team Meeting 1	21/12/10	Primary Source – Author's Minutes
16	The Aerodynamic Caravan	10/02/11	Primary Source - Report Written by Author shared with KTP Team
17	Monthly Meeting 8 Minutes	11/02/11	Primary Source – Author's Minutes
18	Monthly Meeting 9	11/03/11	Primary Source – Author's Minutes

	Minutes		
19	Monthly Meeting 10 Minutes	15/04/11	Primary Source – Author's Minutes
20	Monthly Meeting 11 Minutes	13/05/11	Primary Source – Author's Minutes
21	Monthly Meeting 12 Minutes	01/07/11	Primary Source – Author's Minutes
22	Monthly Meeting 13 Minutes	11/08/11	Primary Source – Author's Minutes
23	Monthly Meeting 14 Minutes	30/09/11	Primary Source – Author's Minutes
24	Electric Only Customer Webpage	01/11/11	Company Marketing Webpage Developed to Support Electric Only Product Launch
25	Streamlined LCA's within Commerical Applications: A Case Study	07/11/11	Presentation given to the University of Bath's Sustainable Energy Research Team (SERT) and shared with KTP Team
26	Managing Directors Retrospective Interview Transcript	24/10/13	Primary Source – Author's Transcription
27	Technical Directors Retrospective Interview Transcript	24/10/13	Primary Source – Author's Transcription
28	Premium Range Caravan Webpage	02/11/14	Company Marketing Webpage to Support Premium Range Caravans and Displaying Curved Rear End Design

Table 31: Full List of References used in the Retrospective Reviews Described in Chapter 4

8.5 Appendix 5: The Introductory Eco-design Process

The outcome of this research is the Introductory Eco-design Process. The seven step process has been developed specifically to support companies in undertaking their first eco-design projects. A reference guide to the Introductory Eco-design Process is provided in Figure 46.

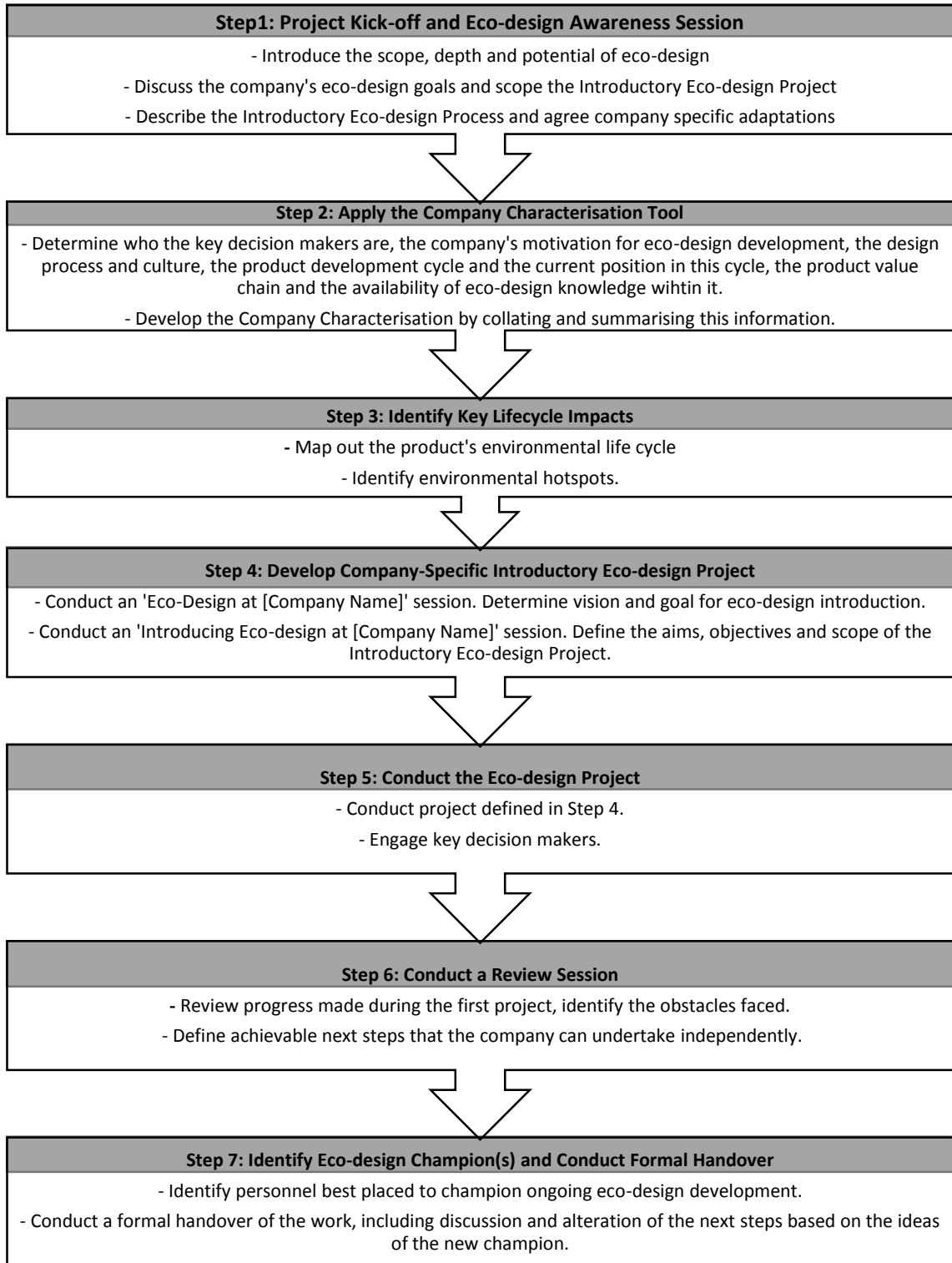


Figure 46: The Introductory Eco-design Process Reference Guide

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